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November 1994

Final Report

Study of Older Child Restraint/Booster Seat Fit and NASS Injury Analysis

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16. Abstract

The Agency initiated this program to study the older child population with respect to the automotive environment. The program had three parts: an analysis of injuries using the National Accident Sampling System database, a restraint/booster seat fit survey with 155 volunteers aged 6-12, and an anthropometry study of the volunteers. The information gathered would provide guidance for future child safety initiatives.

The NASS analysis revealed that older and younger children generally have the same injury patterns and similar injury frequencies in automotive accidents. However, restrained older children are more likely to receive an injury than restrained younger children (37.2% with MAIS 1-7 vs. 29.2% with MAIS 1-7). In the anthropometry study, height, weight, sitting height, and age data were collected for each child, and the averages by age were compared to results from an extensive child anthropometry study conducted by the University of Michigan in 1975. Height and sitting height matched well, while children in the current study appeared heavier. However, the clothing and shoes worn by the current volunteers partly accounts for the difference. In the restraint fit survey, each child sat in the rear seat alone and in three belt-positioning booster seats (Volvo, Kangaroo, Century CR-3) in three vehicles (Ford Taurus, Pontiac Sunbird, Dodge Caravan).

Booster seats greatly improved belt fit over the rear seat alone. The majority of children in this study had better belt fit with the boosters than with the rear seat alone, regardless of size. However, children who could fit well in the boosters and had good or fair belt fits were generally 36 kg or less. Also, it was found that the minimum size child in this study who could use the three-point belts alone had a sitting height of 74 cm, standing height of 148 cm, and a weight of 37 kg. A possible cause of poor belt fit that is specialized to this group of children is the "slouch factor". Children of these ages will scoot forward in a seat to allow comfortable leg positions rather than sitting up straight and putting pressure on the backs of their lower legs. Booster seats seem to prevent slouching by allowing a comfortable leg position while sitting upright.

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METRIC CONVERSION FACTORS

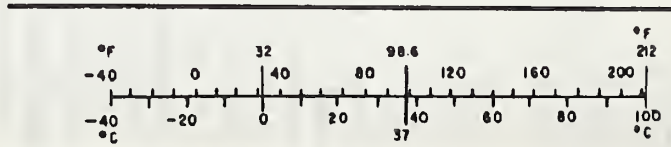
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Department of Transportation
National Highway Traffic Safety Administration

TECHNICAL SUMMARY

Report Title:	Date:
Study of Older Child Restraint/Booster Seat Fit and NASS Injury Analysis	November 1994
Report Author(s): Kathleen DeSantis Klinich, Howard B. Pritz, Michael S. Beebe, Kenneth Welty, Ronald W. Burton	

The Agency initiated this program to study the older child population with respect to the automotive environment. This report describes a survey of how current vehicle restraints meet the needs of children aged 6 to 12 years. It also studied whether belt-positioning booster seats intended for children up to 36 kg actually improved belt fit on older children. As a part of the restraint fit study, a simple anthropometric survey of the child volunteers was also conducted. In addition, the program included an analysis of automotive injury patterns for older and younger children using data from the National Accident Sampling System (NASS) database. The information gathered would provide guidance for future child safety initiatives.

The NASS analysis showed that while older children make up 43.1% of the child occupant population in the NASS database, they sustained 55.4% of the injuries received by children. This probably results from older children wearing restraints less frequently than younger children, with 38.6% vs. 25.7% unrestrained. However, restrained older children are more likely to receive an injury than restrained younger children (37.2% with MAIS 1-7 vs. 29.2% with MAIS 1-7). Wearing restraints does reduce the occurrence of injury for an older child (62.5% uninjured with restraints vs. 36.4% uninjured without restraints). Most of the injuries to all children are minor, and the injury patterns for older and younger children are generally the same.

The anthropometry study and restraint fit survey portions of the program involved 155 children aged 6 to 12. Height, weight, sitting height, and age data were collected for each child, and the averages by age were compared to results from an extensive child anthropometry study conducted by the University of Michigan in 1975. The heights and sitting heights generally matched fairly well, indicating that the cross-section of volunteers was reasonable. The weights in this study were generally higher, leading to the possibility that children today may be heavier than they were 20 years ago.

In the restraint fit survey, each child sat in the rear seat alone and in three booster seats intended for older children, in three different vehicles. The boosters and maximum recommended weights were Volvo (36 kg), Kangaroo (36 kg), and Century (30 kg); the vehicles were a mid-size Ford Taurus, a compact-size Pontiac Sunbird, and a minivan, the Dodge Caravan. Each child was videotaped wearing a three-point belt in each configuration. The films were evaluated with a rating scheme for various fit and posture issues.

Booster seats greatly improved belt fit over the rear seat alone. The Caravan had the worst shoulder belt fits in the rear seat alone and with the boosters, while the Sunbird had the best belt fits in the rear seat

and boosters. The booster seat fit results indicate that the Kangaroo's maximum recommended weight limit may be too high. The majority of children in this study had better belt fit with the boosters than with the rear seat alone, regardless of size. However, children who could fit well in the boosters and had good or fair belt fits were generally 36 kg or less. The sitting heights of these children ranged from 58 to 76 cm, and their standing heights varied from 117 to 152 cm.

The minimum size child for using three-point belts alone is a sitting height of 74 cm, standing height of 148 cm, and a weight of 37 kg. However, a child with the height but a lower weight would also probably have acceptable belt fit, while a child with the minimum weight but not the height may not have an acceptable fit with the belt alone.

A possible cause of poor belt fit that is specialized to this group of children is the "slouch factor". Children of these ages will scoot forward in a seat to allow comfortable leg positions rather than sitting up straight and putting pressure on the backs of their lower legs. Slouching down like this positions the lap belt higher over their abdomens, and makes the shoulder belt come closer to their faces. Booster seats seem to prevent slouching by allowing a comfortable leg position while sitting upright.

1.0 PROJECT DESCRIPTION AND OBJECTIVES

Child restraint research has naturally focused on younger children (aged 0 to 5 years), because their distinctly smaller sizes most obviously would not be accommodated by vehicle restraints designed to protect adults. However, restraint researchers have recently devoted more efforts to the needs of older children (aged 6 to 12 years). In particular, child seat manufacturers have developed belt-positioning booster seats intended for children with maximum weights between 30 and 45 kg. Vehicle manufacturers have also built integrated belt-positioning booster seats intended for larger-sized children. Because manufacturers are building more booster seats intended for children up to 36 or 45 kg, more children will be using them, and the safety protection capability of the seats may become an issue of concern.

The NHTSA initiated the Large Child Dummy Development program to study the older child population with respect to the automotive environment. The project consists of three phases. Phase I, described in this report, investigates how well current vehicle restraints and belt-positioning booster seats meet the needs of children aged 6 to 12 years. The restraint fit study recorded how seat belts fit 155 older children seated in three different vehicles when they were used with and without belt-positioning booster seats. One specific goal was to determine the largest size child who benefitted from booster seats, and the smallest sized child that could effectively use three-point belts alone. As part of the restraint fit study, a simple anthropometric survey of the child volunteers was also conducted. The anthropometry study showed the height, weights, and sitting heights of the volunteers, and compared them to the last detailed anthropometric study conducted in 1975.

Phase I also included an analysis of automotive injury patterns for older and younger children. This consisted of an analysis of child injury data taken from the National Accident Sampling System (NASS) database. Injury patterns between older and younger children were compared to help determine possible future child safety initiatives.

The information gathered in Phase I would show whether another child dummy would be necessary for conducting research on vehicle restraint systems for older children. Currently, the largest child dummy used by NHTSA for research and testing is the size of an average six-year-old. Phase II would use the information collected in Phase I to generally specify the size and characteristics of a larger child

dummy. If the NHTSA should determine that development of a larger child dummy is necessary, Phase III would consist of designing and building a larger child dummy.

2.0 NASS ANALYSIS

2.1 Analysis Procedure

This analysis uses data collected through the National Accident Sampling System (NASS) to study injury patterns in older children within NASS. Injuries are classified several ways: by injury severity (as coded by the Abbreviated Injury Scale), body region injured, system or organ injured, and lesion type. The number of injuries and the maximum AIS injury received by each child are also recorded.

Injury patterns of different groups of children are compared to focus on the injury problems for older children. To begin, the participation in accidents, restraint type, number of injuries received, and maximum AIS score of older and younger children are reviewed to obtain a general idea of the automotive accident environment for children. Accident characteristics for each group, defined by vehicle types, accident types, velocity changes, and seat positions are also checked to determine if both sets of children participate in the same types of accidents. Then, older children are grouped as restrained and unrestrained to see how restraints affect the injury patterns. Next, restrained older children are compared to restrained younger children to see if restraints have the same effect on injury for each group. Unrestrained older and younger children are also compared, to determine if the general automotive environment is more hazardous for either group. Finally, the injuries received by older children are classified as mild or serious. This allows focus of preventive efforts on either the less frequent, but more incapacitating injuries, or the numerous, yet milder injuries. The important findings are then reviewed with respect to automotive safety research.

The National Accident Sampling System (NASS) collects data on automotive accidents from across the United States[1]. The accidents must meet various standards for inclusion in the database, the most significant being that at least one of the vehicles must have been towed for damage. The data are then weighted to represent all police reported towaway motor vehicle accidents for the year.

The weighting factors used are developed statistically from the way the accidents are selected for detailed report. The selected accidents are taken from primary sampling units (PSU) across the United States, which represent different geographic areas and strata (suburban, rural, etc.). In 1988-1990, 36 PSU's were selected; in 1991 only 24 were used. In each PSU, a further sampling process occurs, to obtain a feasible number of accidents for reporting. This sampling process selects cases that represent the range of accident severities occurring in the PSU, with an emphasis on more severe accidents. The weighting factors for each case depend on the probability of that accident being sampled. In addition, for the years 1990 and 1991, the weighting factors are adjusted to match known national totals on automotive accidents.

The information about each case in the NASS file is recorded by investigation teams. The coding scheme for injuries was developed to allow researchers to associate different injuries with their sources. Each injury is characterized by injury severity, the body region affected, system or organ injured, and type of injury. For example, a puncture wound to the chest skin and a puncture wound to the heart have the same body region and type of injury, but different severities and organ/system injured. Clinically, the injuries may be viewed as entirely different because of their severities, but the NASS coding scheme accounts for the similarities, because both injuries would be caused by a penetrating mechanism in the chest area.

The injury severity is coded according to the 1990 Abbreviated Injury Scale (AIS). The files for 1988 and 1989 were updated to match the 1990 version. In addition, an AIS value of 7 is assigned to injuries of unknown severity.

The database allows assignment of an injury to twenty different body regions. Head, neck, face, whole body, and unknown body regions were used without adjustment for this study. The other body regions were grouped into categories more useful for this analysis. Upper extremities includes upper arm, elbow, forearm, wrist, and whole upper limb. Lower extremities includes ankle/foot, knee, lower leg, thigh, and entire lower limb. Thorax includes chest, back, and shoulder injuries, while the pelvis and abdomen injuries were grouped into one category as well.

The NASS coding scheme also associates each injury with the system or organ injured within the body region. Twenty-two system/organ categories exist. This study used the categories of brain,

digestive, eye, integumentary, muscles, all systems in region, and skeletal without change. The remaining systems and organs were grouped together because of their low frequency of occurrence. The "other" class therefore includes arteries/veins, ears, heart, joints, kidneys, liver, nervous system, pulmonary, respiratory, spinal cord, spleen, thyroid, urogenital, and vertebrae.

NASS allows classification of lesions into nineteen categories. The most prevalent types are abrasion, contusions, lacerations, strains, and concussion. While adherence to definitions in the AIS coding manual is encouraged, it appears that the investigators include loss-of-consciousness injuries with concussions. For this study, the categories of dislocation, fracture, and fracture and dislocation were combined. The remaining lesion types were grouped into an "other" category, which includes amputation, avulsion, burn, crush, detachment, puncture, rupture, strain, and transection injuries.

The NASS database is available in a format that can be read by SAS, a language/program designed for statistical analysis[2]. SAS was used to select the data files for all occupants aged less than thirteen years for the years 1988 through 1991. Data from earlier years was not used because the injury information is not as complete.

Two analysis files were created. The first, "Child Occupant", has one observation for every child involved in a NASS accident. This file is used to study the general accident problem for children. The second, "Child Injuries", includes data only for injured children, and has one observation for each injury suffered by a child. The injury pattern sections of this paper refer to this file. SAS was also used to regroup the values for body region, system/organ, and lesion as discussed above.

Another program, SUDAAN[3], provided distributions and statistical analysis. SUDAAN was selected for two main reasons. First, it does not assume that the data were selected from a simple random sample. It accounts for the multi-stage sample design, which involves stratification, clustering, and weighting. Second, SUDAAN could be used to perform a X^2 test for independence between two variables. For example, this would tell if body region injured depended on restraint, or if any differences in the body region distribution between restrained and unrestrained occupants happened by chance.

When comparing injury distributions for two different populations, a X^2 [4,5] test (with alpha= 0.05) was performed to determine if the distributions were statistically different. If so, a Bonferroni

pairwise t-test was performed for each category in the distribution, to determine which particular values were different for the two populations. A Bonferroni t-test was also done for each category within a distribution to check for statistically significant differences. Tables of the distributions used to generate each graph are included Appendix A, together with a summary of the statistical analysis. The distribution percentages that appear in each plot are based on the weighted data. However, early analysis showed that weighting the data did not significantly alter the distributions calculated for unweighted data.

2.2 Characteristics of Children in Accidents

The Child Occupant file was used to study the general characteristics of accidents involving children. Of the child occupants, 56.9% are younger children (aged 0 to 5 years), while the remaining 43.1% are older children aged 6 to 12 years. Although younger children participate in automotive accidents more frequently, they experience only 44.6% of the injuries incurred to all children. Older children seem to receive a disproportionate amount of injury in automotive accidents. However, the fatality rates for older and younger children are the same value of 0.4%.

The automotive restraints worn by children appear in Figure 1. For older children, 38.6% wear no restraints, while 55.9% use seat belts. For the group that wears seat belts, lap belt only (26.9%) and lap and shoulder belts (26.5%) are used at the same rate. Only 0.3% occupy supplementary child seats. Younger children have a higher restraint use rate, with only 25.7% unrestrained. Child seats are employed as frequently as seat belts, with 31.8% and 31.6% usage rates for child seats and belts, respectively. For the belted younger children, the rate of lap belt only use is approximately twice as high as lap/shoulder belt use (19.8% vs. 9.9%).

Several variables were checked to determine if accident characteristics for the two groups of children were similar. Accidents involving both small and large children occur with passenger vehicles in 83% of the cases. The frequencies of accidents in vans, utility vehicles, and trucks, which are involved in the remainder of accidents, are also the same for both groups. The accident severity level, based on change in velocity, is the same for both sets of children. Although change in velocity information is not available for 60% of the cases involving children, the distribution of known velocities for both groups do not differ, and appears in Figure 2. The types of accidents (frontal, side, rearward) are also statistically the same for both groups of children.

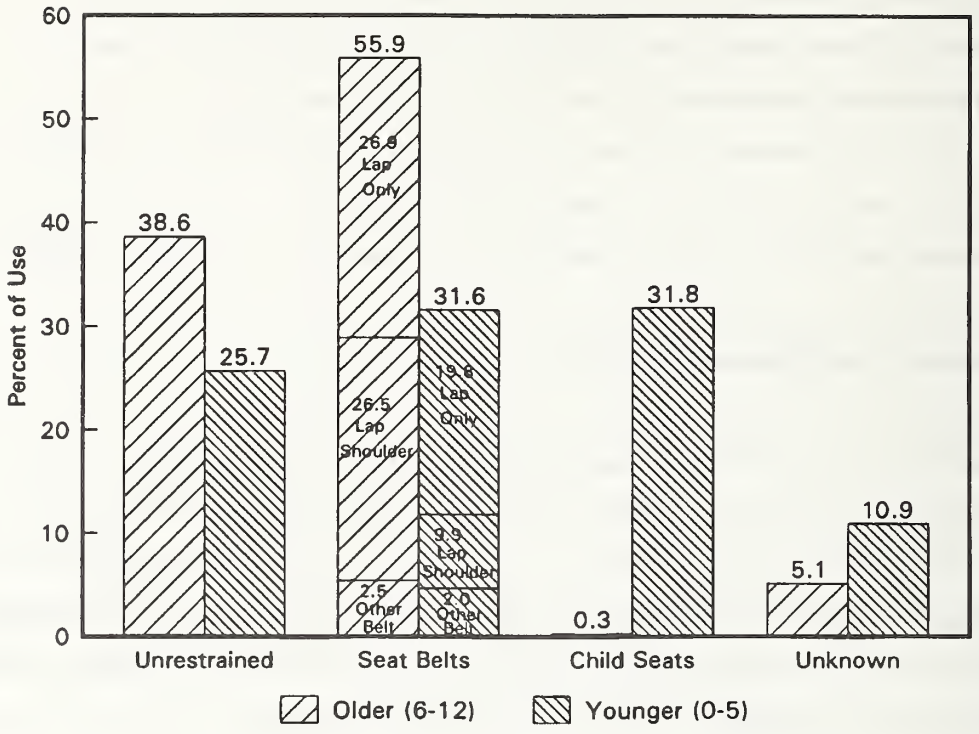

Figure 1 -- Restraint use for older and younger children

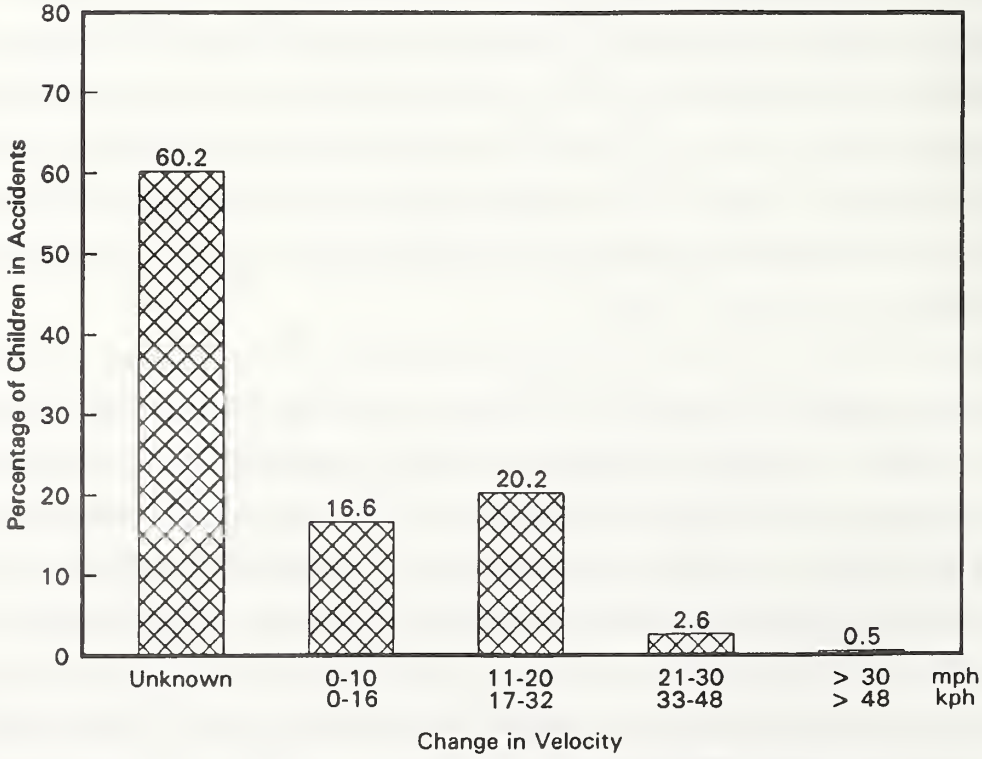

Figure 2 -- Change in velocity for accidents involving children

The only significant change in accident environment between older and younger children is the seat position within the vehicle. As shown in Table 1, a greater proportion of older children sit in the front passenger seat compared to younger children. The remaining seat positions are occupied by older and younger children at the same rates.

TABLE 1 -- Child Position in Vehicle

Seat Position	Percentages of Children		Significantly Different?
	Older	Younger	
Driver	0.7	0.1	No
Front Center	3.9	6.2	No
Front Passenger	38.4	27.0	Yes
Rear Passenger	41.4	47.1	No
Rear Center	8.2	11.7	No
Other	3.4	3.9	No
Unknown	4.1	3.3	No

Figure 3 shows the number of injuries incurred by restrained child occupants. Approximately two-thirds of older and younger restrained children receive no injuries. Each group has a similar proportion receiving either few (1, 2, or 3) or many (8 or more) injuries. Older restrained children more often experience several (4, 5, 6, or 7) injuries. Similar counts appear for unrestrained children in Figure 4. Unrestrained younger and older children are equally likely to suffer no injuries. They also have the same proportion receiving few or many injuries. However, older children are more likely to receive several injuries, as compared to younger children.

The most severe injury levels received by child occupants appear in Figures 5 and 6. For each injured child, the Maximum Abbreviated Injury Scale (MAIS) was recorded. Uninjured children were coded with MAIS values of zero. For restrained children, younger children are more likely to go without injury than older children (70.8% vs 62.8%). Older children have higher rates of MAIS=2. The remaining MAIS levels are the same for both groups of children. For unrestrained children, the distribution of maximum injury severity is statistically independent of child age grouping. In all four distributions, fewer than 10% of the children had MAIS scores rated 2 and higher.

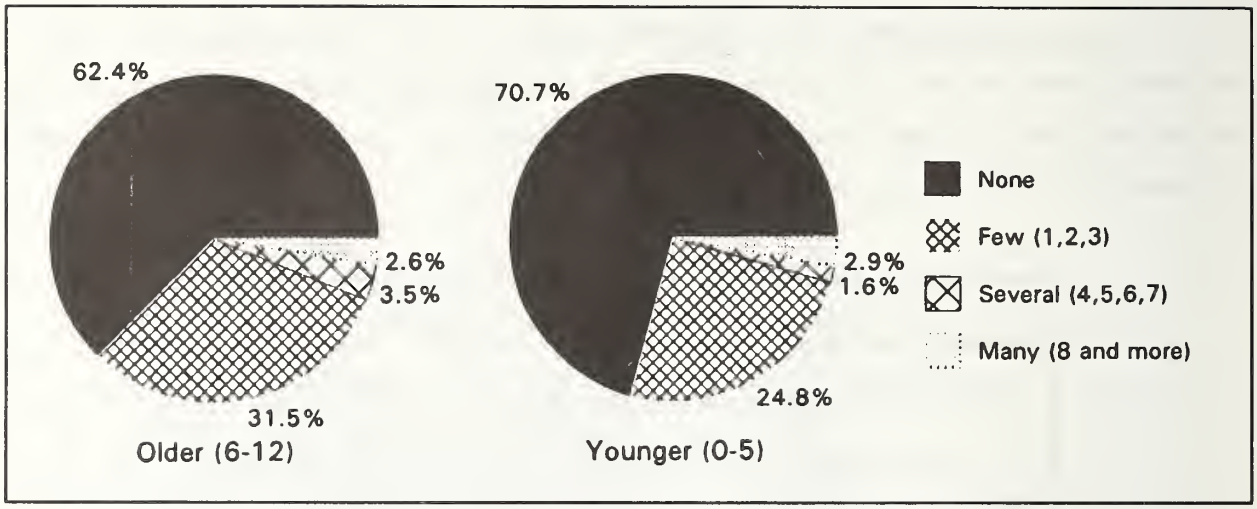

Figure 3 -- Number of injuries received by older and younger restrained children

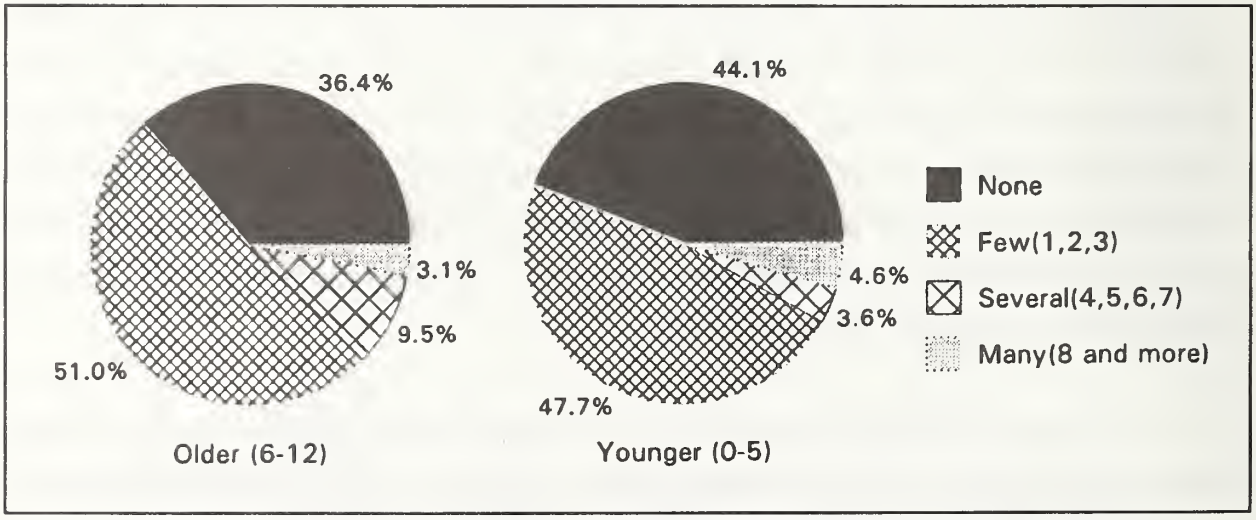

Figure 4 -- Number of injuries received by older and younger unrestrained children

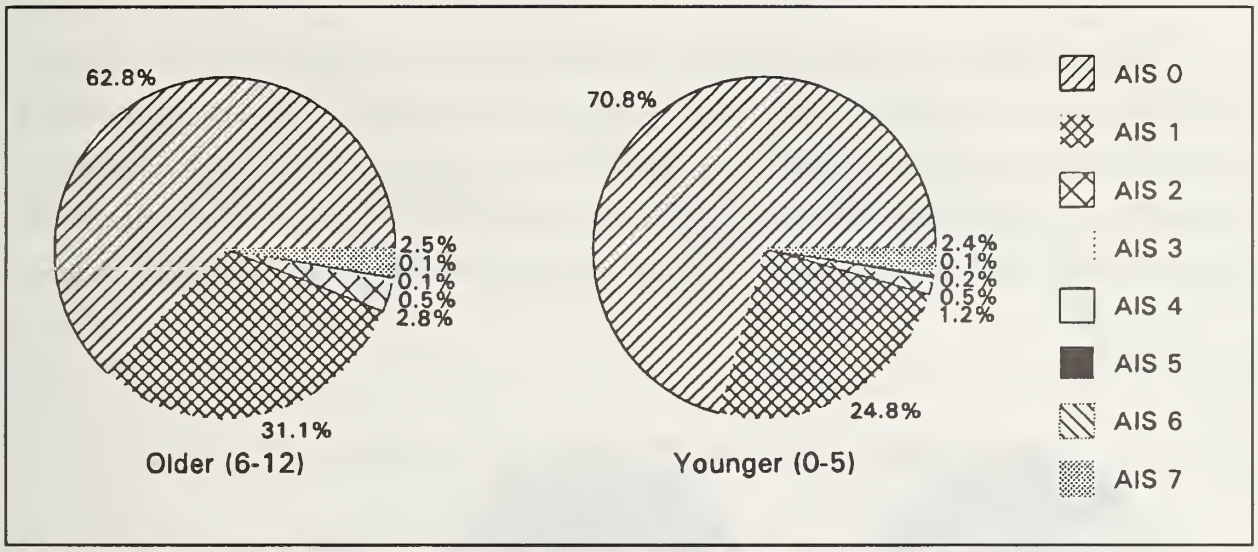

Figure 5 -- Maximum AIS score for restrained older and younger children

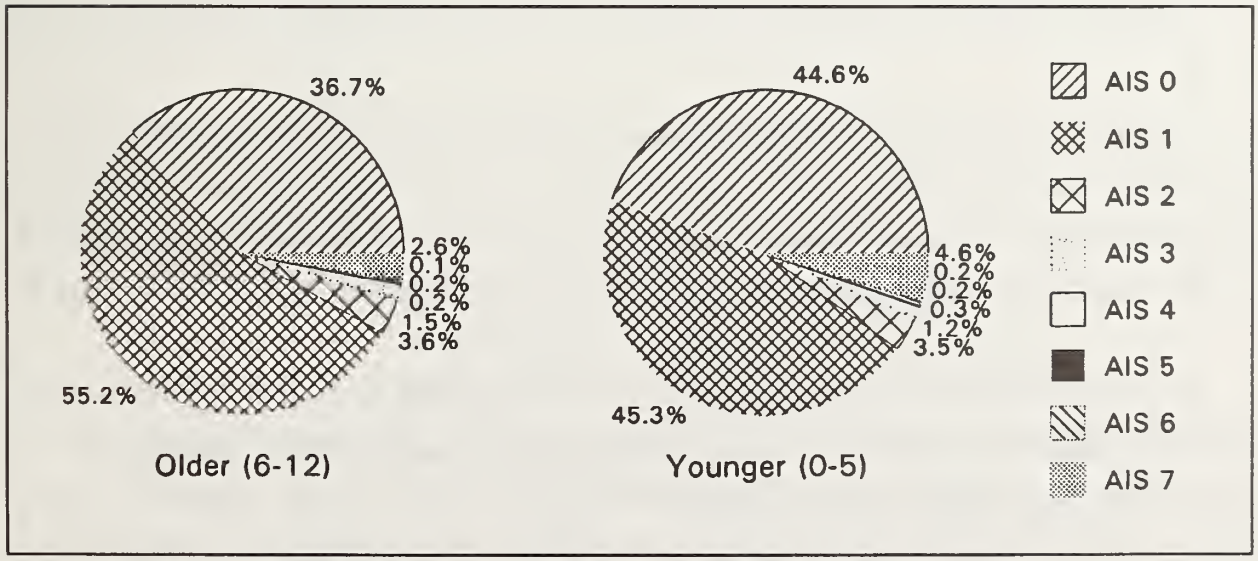

Figure 6 -- Maximum AIS scores for unrestrained older and younger children

2.3 Injury Patterns: Restrained vs. Unrestrained Older Children

Wearing restraints reduces the number of injuries an older child is likely to receive. Figure 7 shows that 62.4% of restrained older children have no injuries, contrasting sharply with only 36.4% of unrestrained children who remain uninjured. The proportion of restrained children experiencing four or more injuries (6.1%) is less than half that of unrestrained children (12.9%). The following analysis looks at injuries to older children, and compares the injury patterns for restrained and unrestrained children.

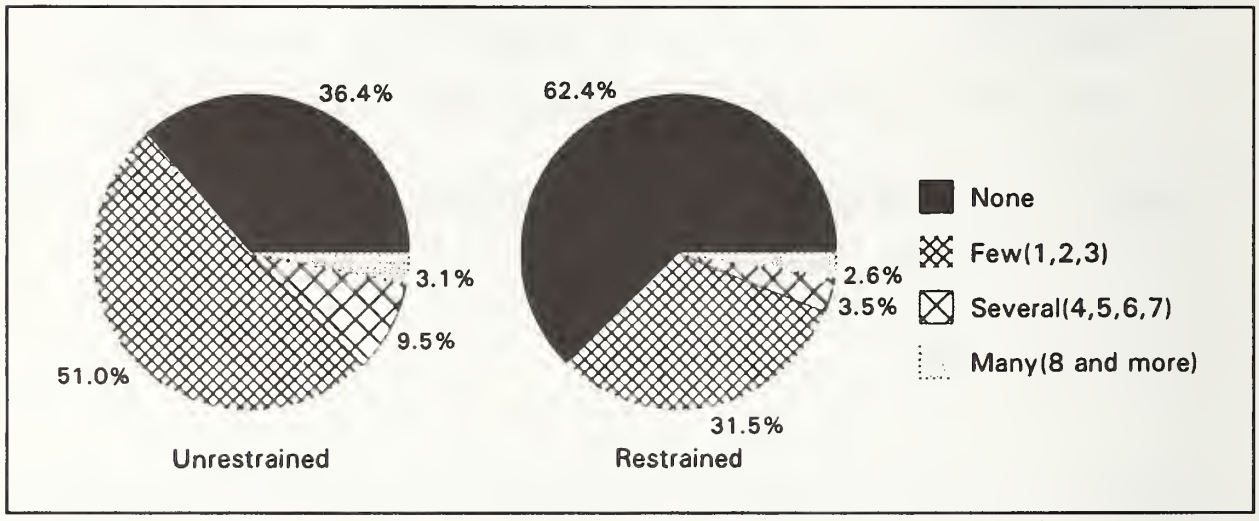

Figure 7 -- Number of injuries received by older restrained and unrestrained children

Figure 8 compares the severities of injuries to restrained and unrestrained injured older children. The severity distributions, based on AIS scores for injuries, are statistically independent of restraint. While restraint reduces the chance of receiving any injury, injured older children have the same severities of injury regardless of restraint. However, the majority of injuries that older children incur are minor.

A study of the injury characteristics of restrained and unrestrained older injured children may help explain the injury severity distribution. The body region injured appears in Figure 9. For older children, wearing a restraint slightly reduces the proportion of injury to the whole body. However, injured children wearing restraints have higher rates of pelvis/abdomen injury, jumping from 2.6% of injuries to unrestrained children to 10.8% of injuries to restrained children. The remaining body regions are injured at statistically the same levels, regardless of restraint. The face is injured at the highest rate.

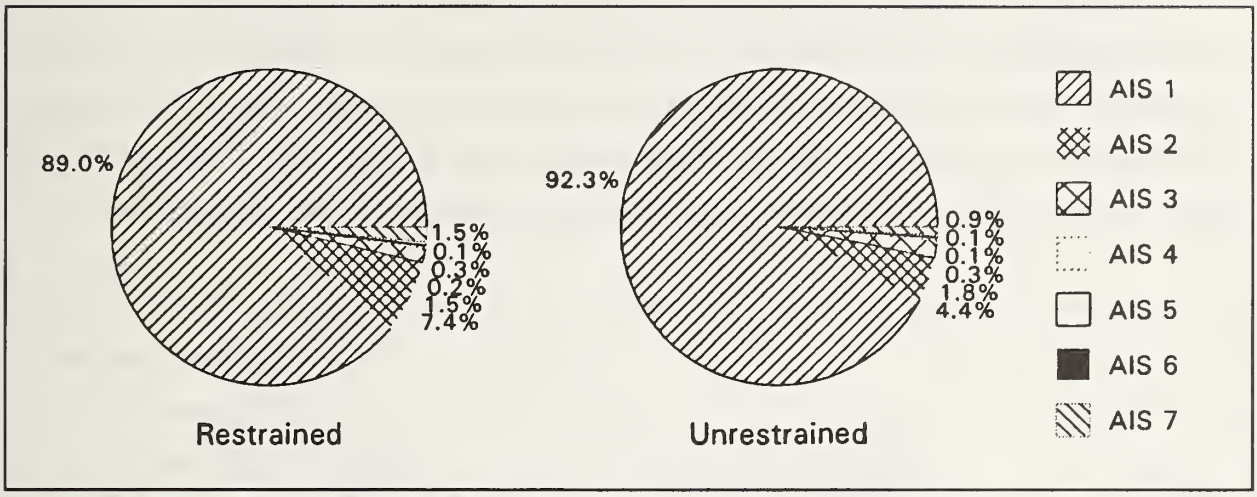

Figure 8 -- Injury severities for older restrained and unrestrained children

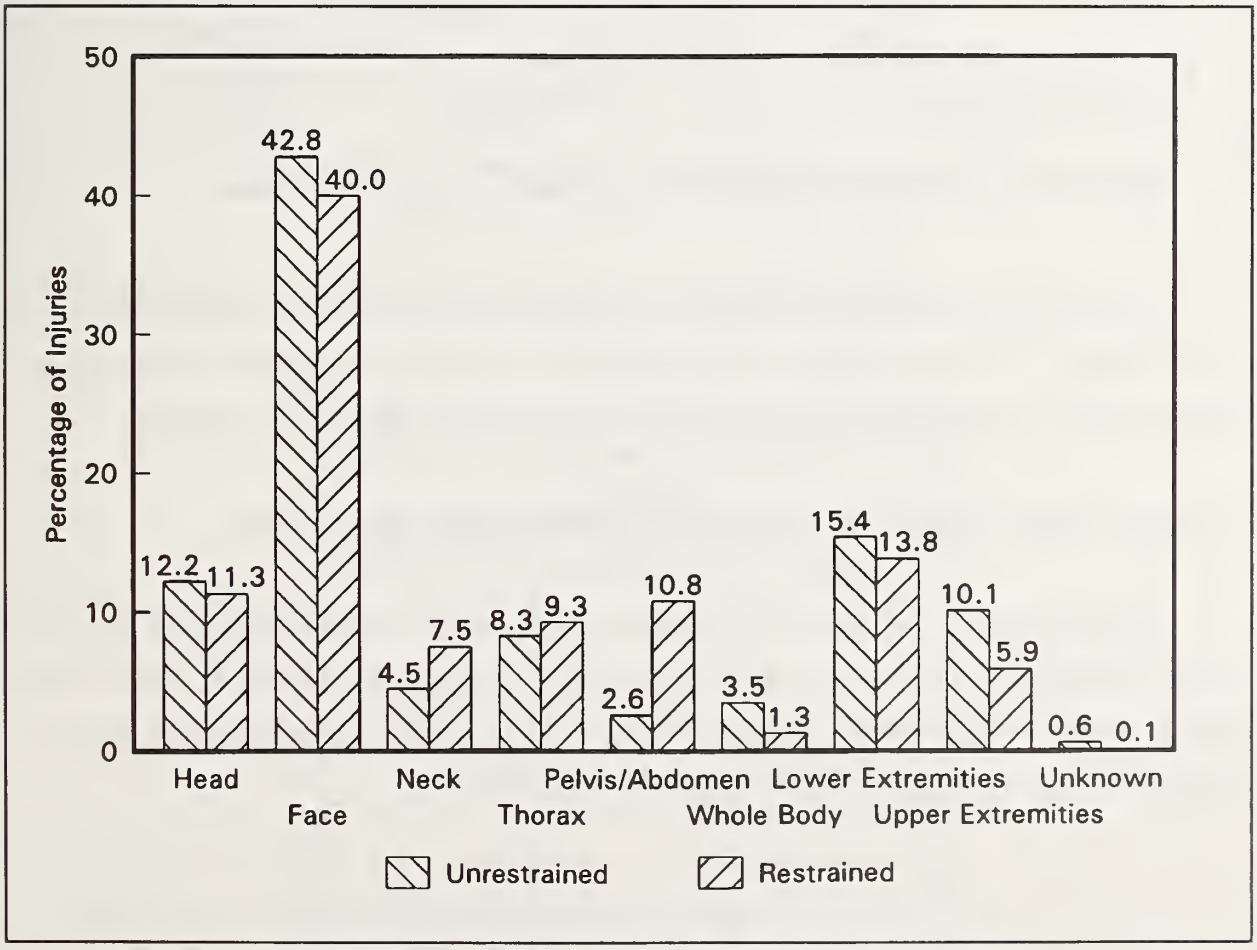

Figure 9 -- Body region injured for older restrained and unrestrained children

Another way of studying injury patterns is to consider the system or organ injured. Figure 10 shows the distributions of injury according to this classification scheme. Integumentary (skin) injuries predominate for both restrained and unrestrained older children, comprising approximately three-quarters of all injuries to older children. The other distributions of injury are the same for both groups, with skeletal, muscular, brain, and other comprising the organs/systems injured most often after the skin.

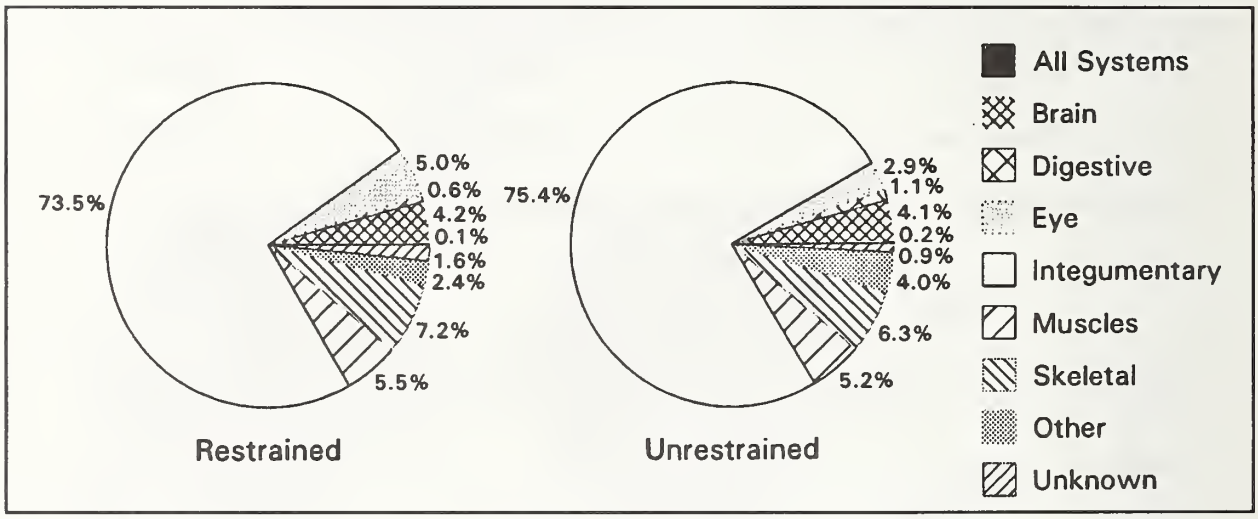

Figure 10 -- System/organ injured for older restrained and unrestrained children

The injuries incurred by older children when classified by lesion type are shown in Figure 11. The plot indicates that most injuries to older children are contusions, lacerations, and abrasions. Statistical analysis demonstrates that lesion type is independent of restraint for older children.

2.4 Injury Patterns: Older vs. Younger Restrained and Unrestrained Children

The injury patterns of older and younger restrained children were also compared to study how restraints affect injury patterns for each group. The severities of the injuries suffered by the two groups appear in Table 2. The distributions of injury severity for the two groups are statistically the same, with only a small proportion of serious injuries received by each group.

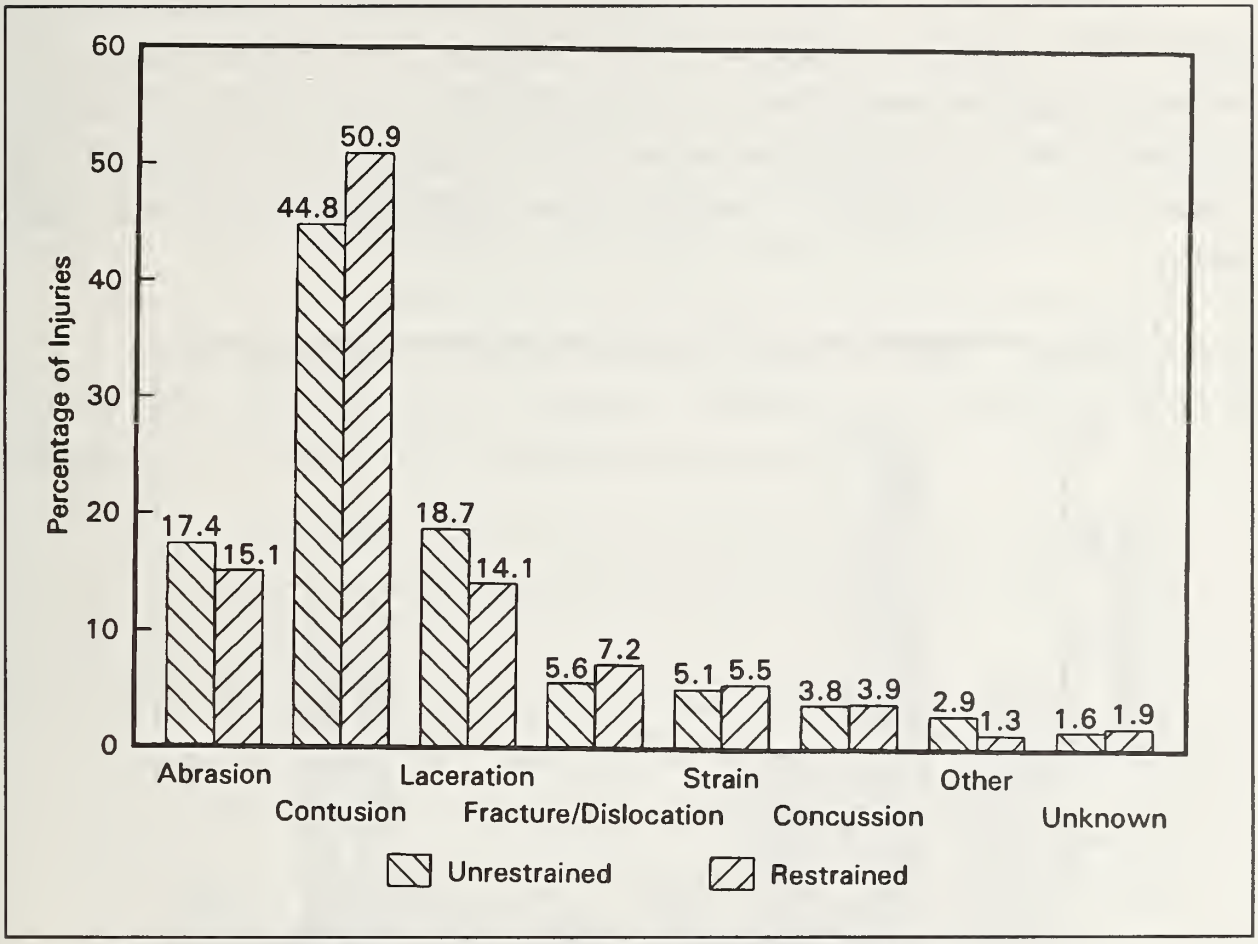

Figure 11 -- Lesion type for older restrained and unrestrained children

TABLE 2 -- Injury Severities of Restrained Children		
AIS Level	Older	Younger
1	89.0	91.7
2	7.4	4.5
3	1.5	1.8
4	0.2	1.8
5	0.3	0.3
6	0.1	0.2
7	1.5	0.6

The same statistical conclusion is true for the distribution of body region injured and system/organ injured. The distributions for restrained older children that appeared in Figures 9 and 10 are generally the same for younger restrained children as well, except that younger children receive more injuries to the digestive system. Some differences exist between older and younger restrained children when looking at lesion type, as shown in Figure 12. Older children incur slightly more strain injuries than younger children.

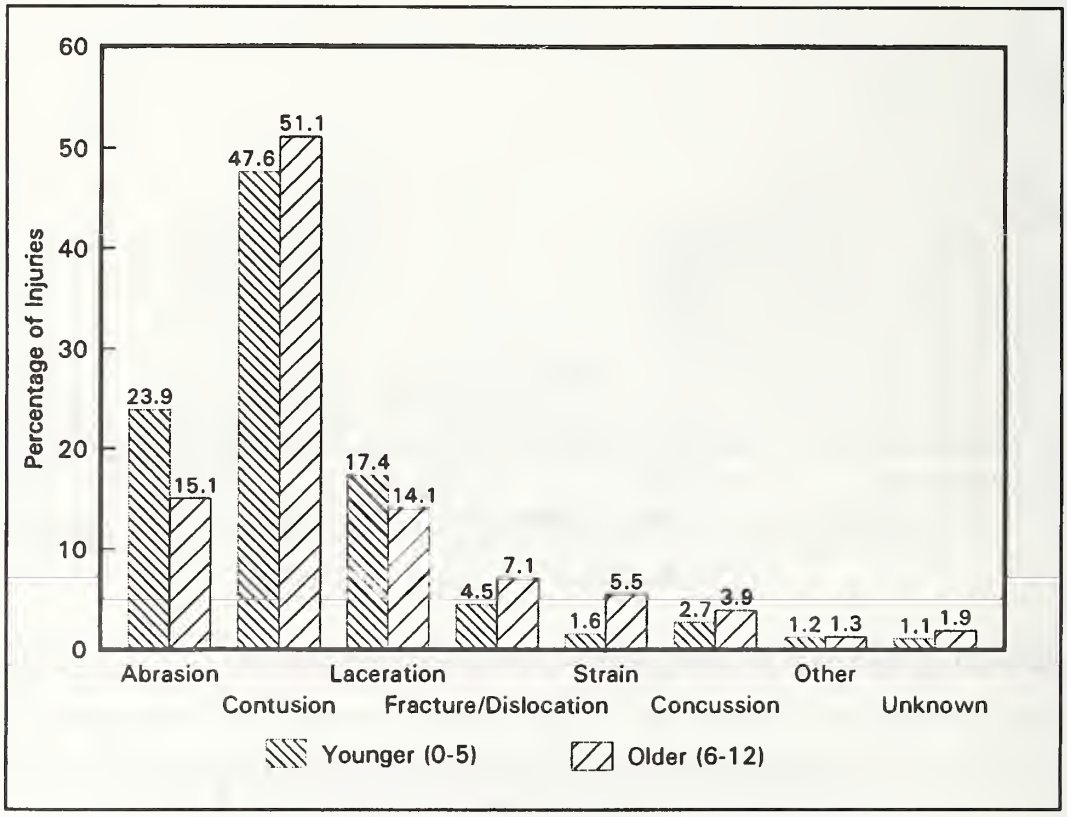

Figure 12 -- Lesion type for older and younger restrained children

For unrestrained children, the distributions of injury severity, body region injured, system/organ injured, and lesion type that were presented previously for older unrestrained children also hold for younger unrestrained children.

2.5 Injury Characteristics of Mild and Severe Injuries in Older Children

The following analysis looks at differences between mild and serious injuries. Mild injuries, considered to be of AIS severity 1 or 2, comprise most of the injuries for restrained and unrestrained older children. The remaining AIS 3, 4, 5, and 6 injuries are classed as serious injuries. Although these

injuries account for only 2.1% and 2.3% of the injuries sustained by restrained and unrestrained older child passengers, they most often cause death or long-term incapacitation. While it remains important to eliminate the more severe injuries, minor injuries also deserve preventive efforts because of their high frequency. To guide injury prevention for older children, the characteristics of each injury level are compared to study ways of preventing both serious and mild injuries.

The body regions injured for mild and serious injuries appear in Figure 13. Injuries to the head, face, and neck are the statistically different categories. Mild injuries occur frequently to the face, lower extremities, thorax, and head. Most serious injuries affect the head.

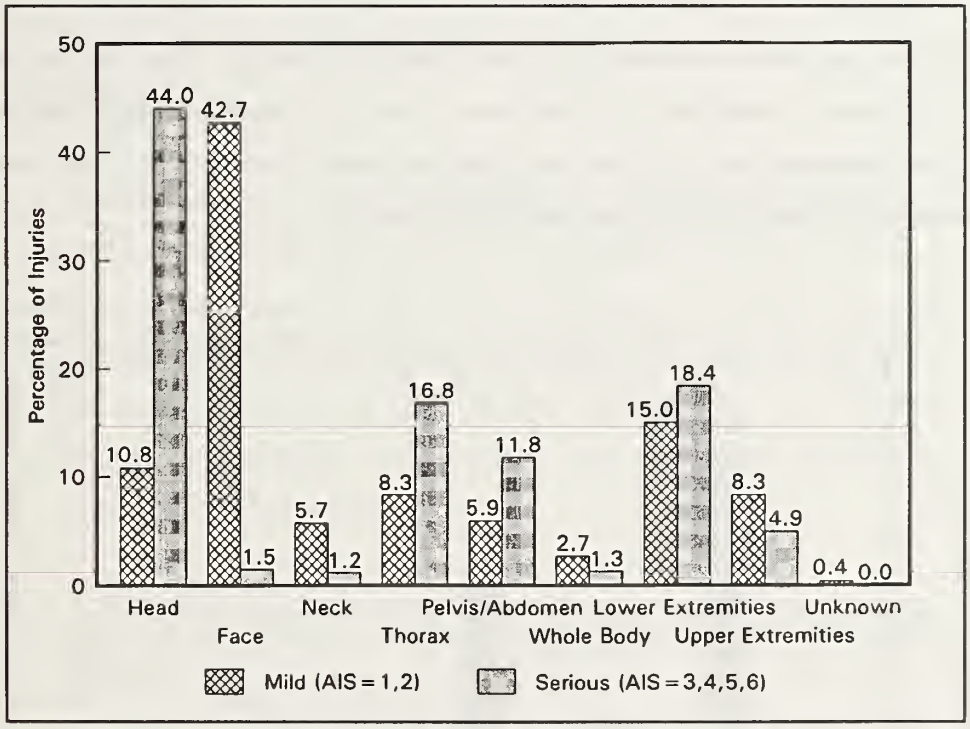

Figure 13 -- Body region injured for mild and serious injuries to older children

Almost all of the system/organ injured categories depicted in Figure 14 are statistically different when comparing mild and serious injuries. Only injuries to the whole body and digestive systems are the same for the two classifications. Most of the mild injuries received by older children are integumentary. For the serious injuries, the most likely system or organ injured is the skeletal, followed by the brain and other systems.

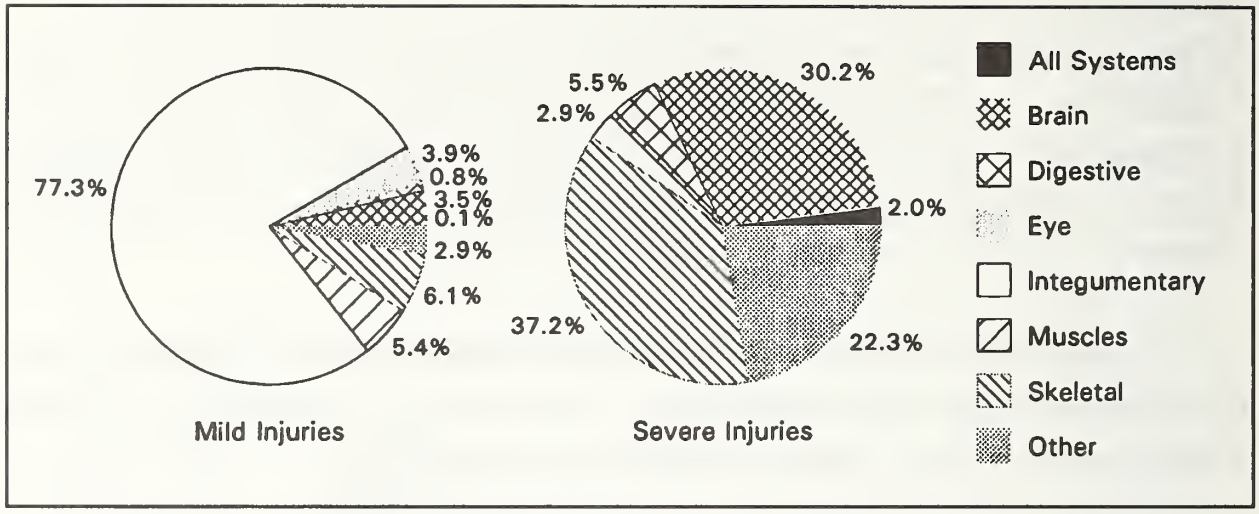

Figure 14 -- System/organ injured in mild and serious injuries to older children

The lesion type of mild and serious injuries appears in Figure 15. Mild injuries are most often classified as contusions, lacerations, and abrasions. Serious injuries are most often fractures and concussions, but contusions and lacerations also comprise a major portion. All of the lesion categories (except lacerations and other) differ for the two injury classes.

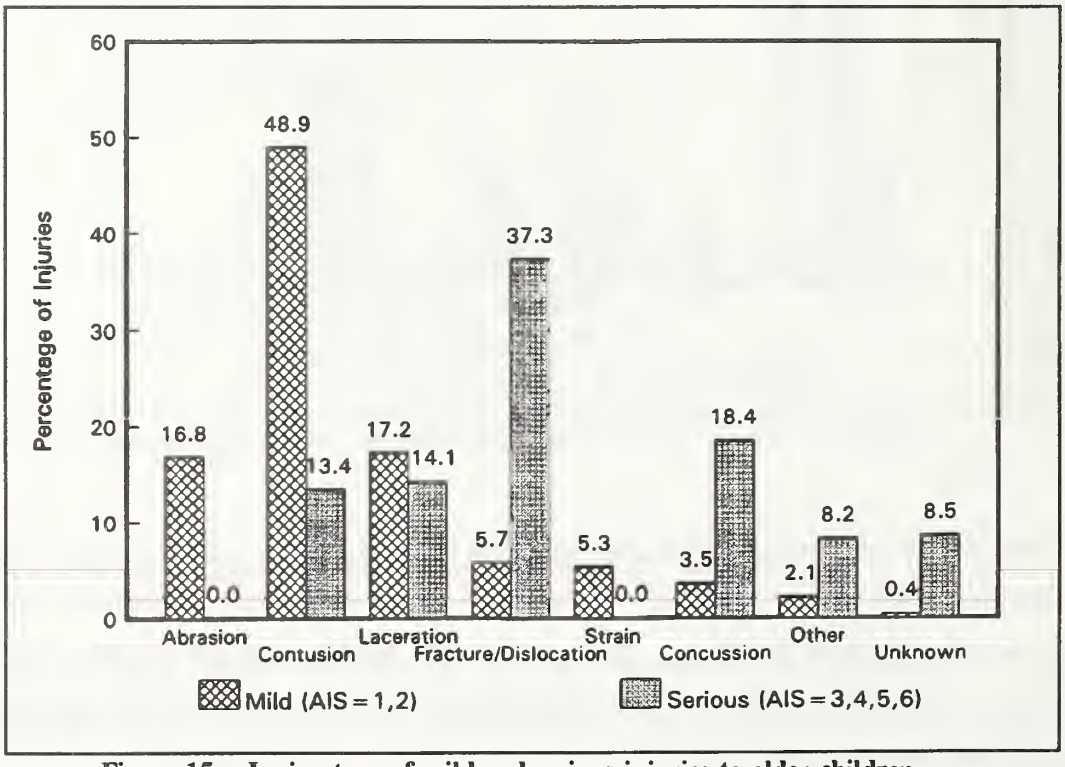

Figure 15 -- Lesion type of mild and serious injuries to older children

2.6 Implications for Child Automotive Safety Research

The previous analysis reveals these characteristics about injury patterns to older children:

- Older children make up 43.1% of the child occupant population in the NASS data base but sustain 55.4% of the injuries received by children.

- Older children wear restraints less frequently than younger children (38.6% vs. 25.7% unrestrained).

- Restrained older children are more likely to receive an injury than restrained younger children (37.2% with MAIS 1-7 vs. 29.2% with MAIS 1-7).

- Wearing restraints reduces the occurrence of injury for an older child (62.5% uninjured with restraints vs. 36.4% uninjured without restraints).

- Restrained injured children have a higher proportion of pelvis/abdominal injuries and fewer whole body injuries. The injuries for all older children are primarily integumentary, and consist of abrasions, contusions, and lacerations.

- Older children generally have the same injury patterns as younger children.

- Severe injuries to older children most often affect the head. The skeletal, brain, and other systems are involved most frequently. Fractures, concussions, lacerations, and contusions are the most frequent lesion types.

- Mild injuries to older children occur frequently to the face, lower extremities, and head, and are primarily integumentary. Contusions, abrasions, and lacerations are the most common lesions.

This investigation of the NASS database shows that older children have similar injury patterns to younger children, but are injured more frequently. The lower restraint use of older children is partially responsible for the higher injury rate, but restrained younger children have lower rates of injury than restrained older children. This information indicates that future safety initiatives should address both older and younger children.

3.0 ANTHROPOMETRY STUDY

3.1 Volunteer Selection

The anthropometry study and fit survey required the use of child volunteers.[1] The principal at Edgewood Elementary School in Marysville, Ohio agreed to let students in grades one through five participate in the survey. The school was chosen because its size would provide enough volunteers (approximately thirty per grade) and because of its proximity to NHTSA's Vehicle Research and Test Center (VRTC). The school population does not necessarily match the national distribution by race or economic status. However, comparisons between the size distributions of the VRTC volunteers and those from more extensive measurement studies would help to ensure that the sample population was reasonable.

To implement the program, VRTC first sent letters to parents explaining the program. At that time, parents could refuse to have their children be considered for participation in the program. After the students returned their initial permission forms, they heard presentations on crash test dummies and the measurement program during their physical education classes. The students were then asked to volunteer. Most of the students in each classroom were interested, so all the names were collected and eight names were selected from each of four classrooms per grade. Names of students whose parents

[1]These portions of the program were conducted in compliance with NHTSA Order 700-1, "Protection of the Rights and Welfare of Human Subjects in NHTSA-sponsored Experiments."

previously refused permission were not included. Students who did not volunteer were usually overweight, or boys who did not want to miss part of their physical education class to participate. The volunteers received another, more formal permission slip, which was signed by their parents before they were able to participate. A total of 155 volunteers received permission. The distribution of volunteers by gender and age appears in Table 3.

TABLE 3 -- Distribution of Volunteers by Gender and Age

	7	8	9	10	11	12
Boys	14	13	17	16	14	2
Girls	13	16	17	15	17	1
Total	27	29	34	31	31	3

3.2 Anthropometric Measurements

A simple anthropometry study of the volunteers constituted the first phase of the program. Each child's weight, height, sitting height, age, and birthdate were recorded. The age used was an exact calculation as of March 1, 1993. The volunteers were also photographed from the front and side while sitting in a reference chair. These photos would allow comparison between volunteers and approximations of pertinent anatomical measurements. The children also wore a target "necklace" which would be helpful when reviewing the reference chair pictures and in-vehicle videotapes. Figures 16 and 17 show samples of the photos. Each child was also assigned an identification number. The distribution of volunteers according to height and weight is found in Table 4.

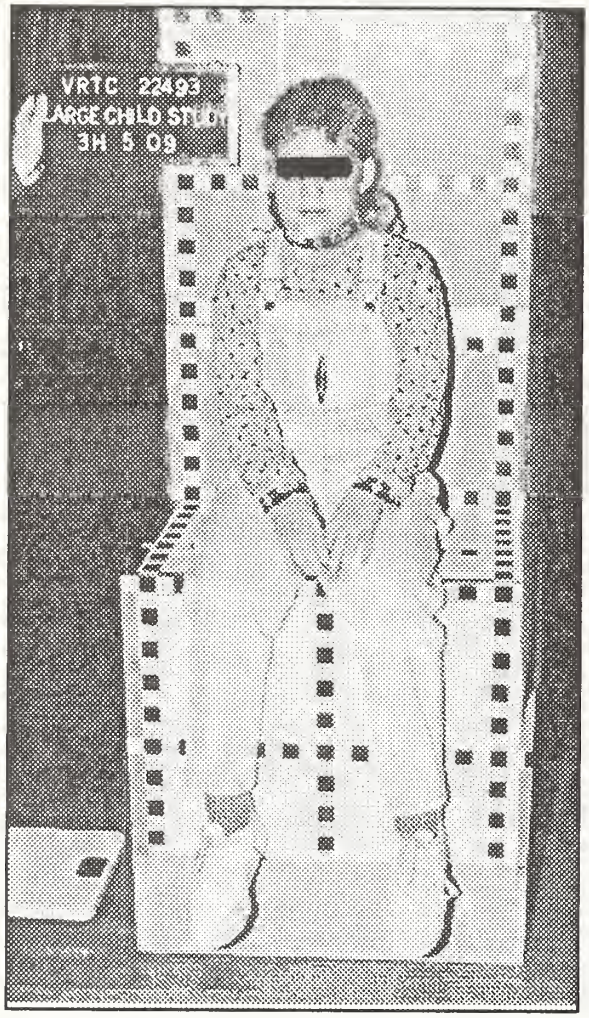

Figure 16 – Front view of a volunteer seated in reference chair

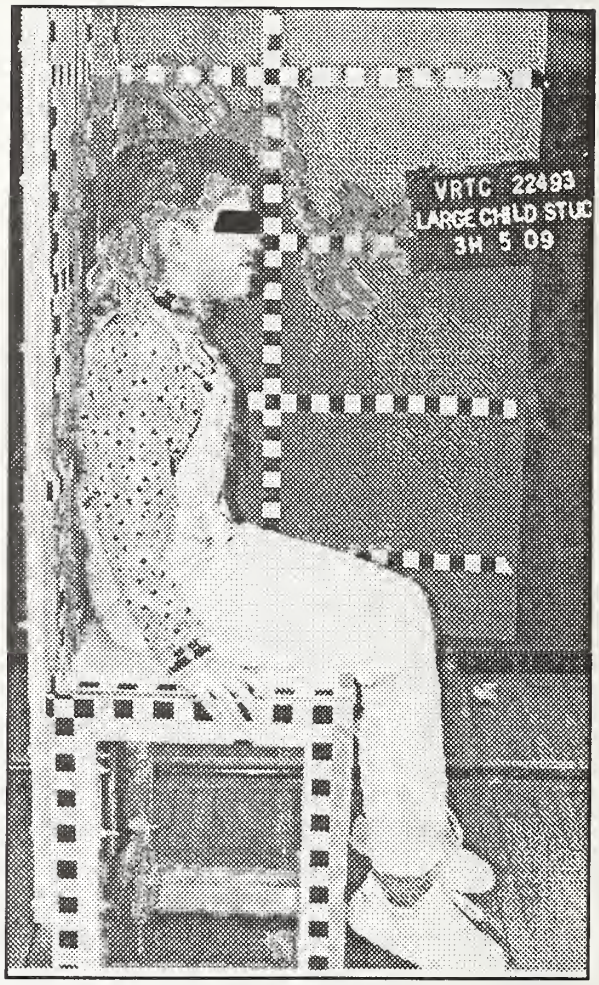

Figure 17 – Side view of a volunteer seated in reference chair

TABLE 4 – Distribution of Volunteers by Weight and Height							
Weight (kg)	Height (cm)						
	112-117	118-124	125-132	133-140	141-147	148-155	156-168
< 23	5	13	3				
24-27		9	18	6			
28-32	1	1	9	17	11		
33-36			2	7	2	2	
37-41			2	3	7	7	
42-50				2	9	7	1
51 +					2	5	6

3.3 Anthropometric Analysis

To check the validity of the VRTC data, the weight, height and sitting height data were compared to data from other studies. The most extensive anthropometric study of older children was conducted by the University of Michigan (UM) in the mid 1970's[6]. The study measured the anthropometric characteristics of 4127 children aged 0 to 18 years. The children were selected to represent the United States child population with regard to race, demographic, and socio-economic factors. The large sample size and careful sample selection process make the UM study an excellent benchmark for comparison. The average, minimum, and maximum weights, heights, and sitting heights by age for the VRTC and UM studies appear in Tables 5 and 6.

The sitting height measurements from the VRTC study matched the UM data the best. This indicates that the VRTC sample of children may be generally considered as well-distributed as the UM study, even though the number of participants was much smaller. The height measurements from the current study are slightly higher than those of the UM study. However, the VRTC volunteers wore shoes, while the UM participants were barefoot. In a test using five of the VRTC volunteers, the difference in height caused by shoes averaged 2.2 cm, accounting for some of the difference.

TABLE 5 -- VRTC Large Child Measurement Survey Weight and Heights by Age										
Age	N	Weight (kg)			Height (cm)			Sitting Height (cm)		
		Avg	Lo	Hi	Avg	Lo	Hi	Avg	Lo	Hi
7	27	24.3	15.0	39.9	123	112	137	64	58	70
8	29	28.1	20.9	45.4	130	119	146	64	60	75
9	34	32.0	20.9	59.9	137	119	150	71	61	79
10	31	36.5	23.6	56.2	142	126	156	73	64	79
11	31	43.0	22.2	81.2	148	130	166	75	65	88
12	3	45.7	38.1	52.2	150	147	152	77	76	78

TABLE 6 -- UM Child Measurement Study Weight and Heights by Age										
Age	N	Weight (kg)			Height (cm)			Sitting Height (cm)		
		Avg	Lo	Hi	Avg	Lo	Hi	Avg	Lo	Hi
7	227	23.7	15.4	43.6	121.2	106.3	133.8	65.8	56.6	73.5
8	198	26.6	17.6	54.2	126.9	111.5	140.6	68.2	59.7	75.6
9	257	29.7	19.6	60.0	133.0	117.8	150.3	70.3	61.2	78.5
10	258	33.1	22.2	69.0	137.7	120.1	159.0	72.1	64.5	81.6
11	282	37.2	20.7	80.0	143.3	122.0	151.1	74.5	65.2	84.6
12	287	40.3	26.1	77.8	148.8	132.8	172.4	76.7	67.1	87.7

The average weights between the two studies are the most different. The average weight for each age group in the current study is higher than in the UM study. The differences become larger with increasing age. To check this finding, two other studies were also compared. The first is a 1979 study by the National Center for Health Statistics (NCHS)[7]. The second is a VRTC analysis of child occupants in the 1988-1991 National Accident Sampling System (NASS) database. The average heights and weights by age are found in Table 7. Figure 18 plots average height vs. weight by age for all four studies. Comparison between the older and newer studies shows that while average heights have not changed, average weights seem to have increased in older children.

TABLE 7 -- Average Heights and Weights by Age

Age	Average Height (cm)				Average Weight (kg)			
	UM (1975)	NCHS (1979)	NASS ('88-'91)	VRTC (1993)	UM (1975)	NCHS (1979)	NASS ('88-'91)	VRTC (1993)
7	121.2	121	118	123	23.7	23	26	28
8	126.9	127	127	130	26.6	28	30	28
9	133.0	132	132	137	29.7	28	33	32
10	137.7	137	137	142	33.1	32	37	37
11	143.3	143	145	148	37.2	36	41	43
12	148.8	150	151	150	40.3	40	47	46

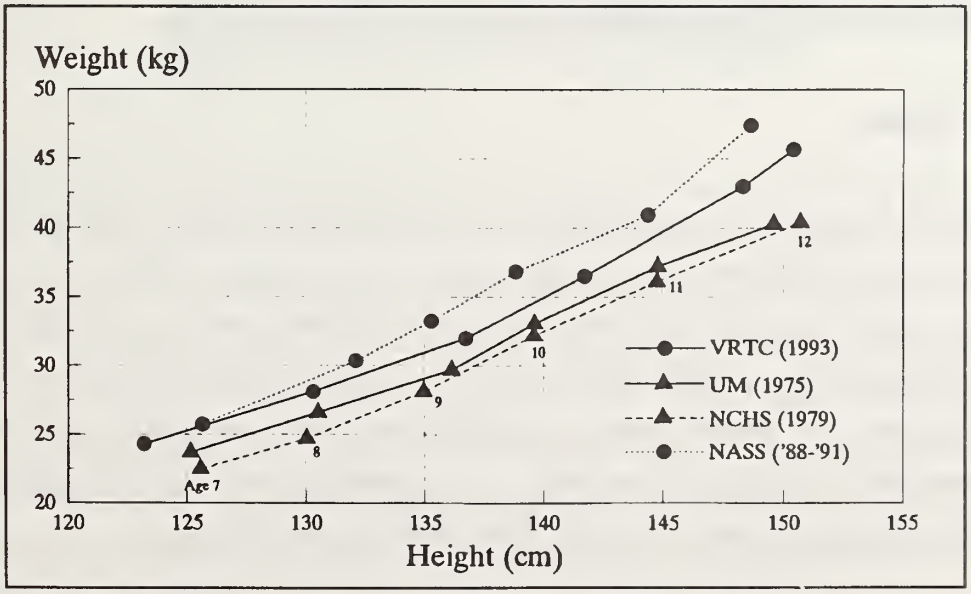

Figure 18 -- Average heights and weights by age in four studies

The data collected from the anthropometry study was used to study the relationship between sitting height and height. Figure 19 shows the linear relationship between these two variables. The expression for sitting height as a function of height, where both dimensions are in centimeters, is SH = 0.498*HT + 2.249. The R^2 value for the fit is 0.89. Since the volunteers wore shoes, the constant includes the effect of heel height.

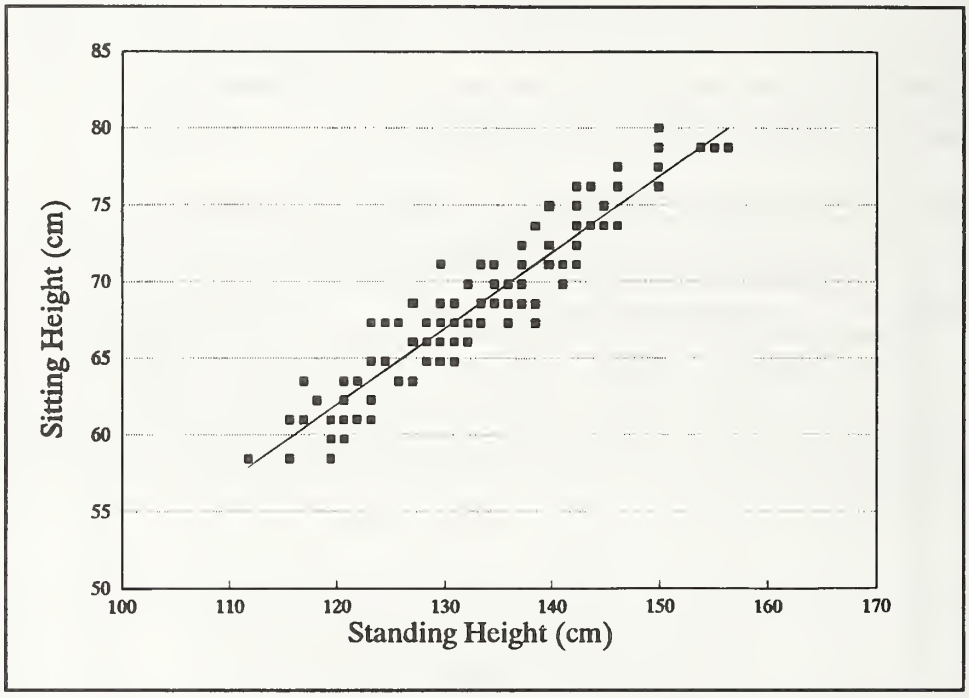

Figure 19 – Sitting height vs. height relationship

4.0 BOOSTER AND RESTRAINT FIT SURVEY

4.1 Survey Design

During the survey's initial planning stages, four belt-positioning booster seats were commercially available. The recommended height and weight ranges for each seat appear in Table 8. The instructions also cautioned against using the seats if the center of the child's head rose above the vehicle seat back. The Century CR-3 and Gerry Double Guard boosters have similar designs, so only one of these two was tested. The Century was selected because of its higher sales volume and higher upper weight limit. Built-in booster seats found in several minivans were not selected because they are designed for smaller sized children. Figure 20 shows the Century, Volvo, and Kangaroo booster seats.

TABLE 8 -- Recommended Height and Weight Ranges for Belt-Positioning Booster Seats				
Seat	Min Height (cm)	Max Height (cm)	Min Weight (kg)	Max Weight (kg)
Volvo Booster	117	137	23	36
Kangaroo Booster			23	36
Century CR-3			11	30
Gerry Double Guard	84	130	14	27

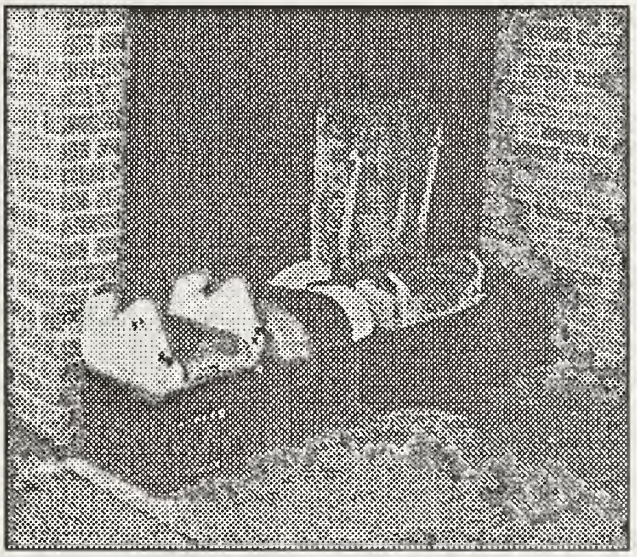

Figure 20 -- Century, Volvo, and Kangaroo booster seats

Vehicle selection resulted from compromise among several factors. An intermediate car, compact car, and minivan (Ford Taurus, Pontiac Sunbird, and Dodge Caravan) were chosen. These vehicles represented the prominent manufacturers and highest-selling makes and types of vehicles. While small pick-ups were more frequently purchased than minivans, a minivan was selected for this program because more families with children would be expected to prefer minivans. The test vehicles have bucket, bench, and captain's chair seats. The Taurus is a four-door, while the Sunbird is a two-door, which would vary interior compartment space. All vehicles have three-point belts in the back seats. Table 9 and Figure 21 contain pertinent measurements for each rear seat and restraint. The changes that result by including each booster seat are also noted.

TABLE 9 -- Vehicle Rear Seat Interior Measurements				
	Label	T	S	C
y-distance between inboard and outboard anchors (mm)	A	483	406	516
y-distance between outboard and shoulder anchors (mm)	B	114	0	70
x-distance between shoulder and outboard anchors (mm)	G	448	394	273
z-distance between shoulder and outboard anchors (mm)	D	775	591	997
cushion depth (mm)	E	521	470	508
cushion height to floor (mm)	F	381	311	381
with Volvo		528	397	514
with Kangaroo		488	476	0
with Century		470	432	465
cushion angle from horizontal (deg)	G	19.4	16.0	19.0
with Volvo		21.0	23.8	18.8
with Kangaroo		17.8	17.9	
with Century		15.5	17.7	9.7
back angle from vertical (deg)	H	25.8	24.0	22.0
with Kangaroo		27.0	26.4	

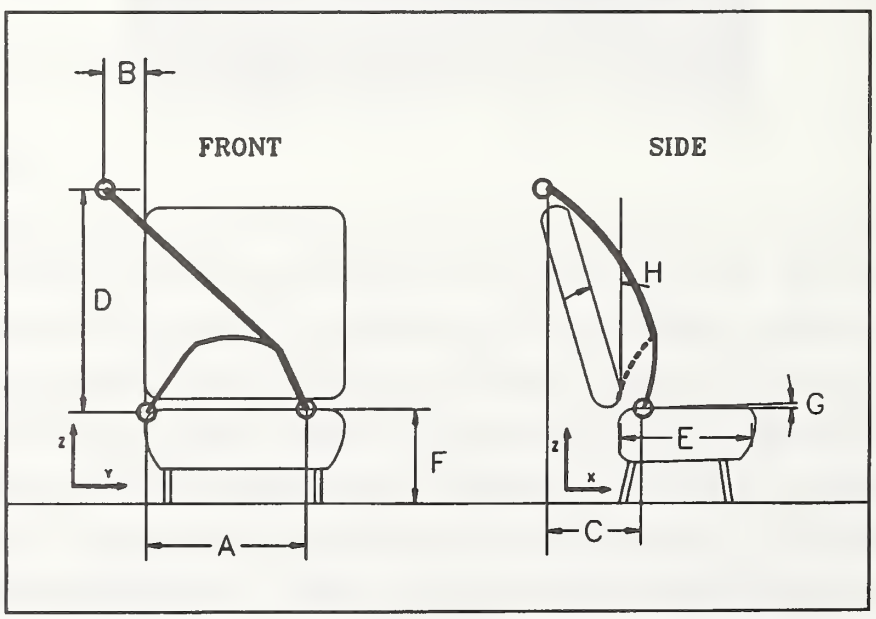

Figure 21 -- Locations of vehicle rear seat interior dimensions

4.2 Survey Procedure

Once the anthropometric measurements were taken, the vehicle restraint survey was begun. The volunteers were excused from their physical education classes one at a time to participate. Since the vehicles were outside, the volunteers wore coats as required by the weather. In the first session with each child, the volunteer tried out the booster seats to see if he or she could fit. Unless the child was uncomfortable, the seat was used regardless of the recommended height/weight requirements. If the student could not fit into any of the booster seats, he or she sat in the front seat instead, with the seat adjusted to the foremost and rearmost positions. Barring a few make-up days, all of the volunteers were surveyed in one vehicle before proceeding to the next one. Each session took approximately ten minutes.

Figure 22 – Contoured seat of Caravan would not allow proper positioning of Kangaroo Booster.

The volunteers first sat in the vehicle's rear seat on the passenger side. If needed, the project technician assisted the students in buckling the three-point belt. The students were asked to try to sit up as straight as they could, which they did to varying degrees. The volunteers also wore a target "necklace", which could be matched to the photographs taken earlier in the reference chair. The engineer then videotaped the volunteer from three to five angles, depending on the vehicle. After the rear seat position was filmed, the process was repeated with the three booster seats. However, the Kangaroo was unable to fit in the contoured captain's chair seat of the minivan, as illustrated in Figure 22. The volunteers were asked to remember which seat/position they liked best; the favorites were recorded at the end of each session.

4.3 Evaluation Procedures

On completion of the survey, an evaluation scheme was developed to assess each vehicle/seat combination, hereafter referred to as an observation. Several researchers tested the proposed rating

scheme on a sample of 10 volunteers, to arrive at "consensus" definitions for each category. The chief evaluator, who also conducted the survey, then rated each observation in the categories found below using the group definitions. Photos that illustrate different degrees of lap belt fit, shoulder belt fit, slouch, and leg angle appear in Appendix B.

SHOULDER BELT FIT: Position of the shoulder belt over the child. Ratings include in face, against neck, on shoulder but too close to neck, centered on shoulder, on shoulder but too close to arm, and over arm.

LAP BELT FIT: Position of the lap belt over the child. Ratings include flat over legs, low over pelvis, over pelvis, over abdomen, and approaching ribcage.

BOOSTER FIT: Fit of child in booster seat; each seat required a different rating system. For the Century, ratings include could not fit, snug fit, and comfortable fit. For the Kangaroo, ratings were primarily based on the position of the child's shoulders relative to targets located on the seat back sides. Ratings include could not fit, tight fit (shoulders covered entire target), medium fit (shoulders covered half of targets), snug fit (shoulders covered part of targets), and comfortable fit (shoulders within seat back sides). For the Volvo, ratings include could not fit, tight fit (child could fit in seat, but belt could not be routed properly), snug fit, and comfortable fit.

SLOUCH: Child's posture in the seat, usually judged from pelvis angle and space between the seat back and child's buttocks. (The contoured seat of the Caravan made it difficult to judge slouch in that vehicle). Ratings include sitting up straight, almost straight, slightly slouched, and extremely slouched.

SEAT POSITION: Child's position in the seat. Ratings include extremely inboard, slightly inboard, centered in seat, slightly outboard, and extremely outboard.

LEG ANGLE: Angle of child's thighs relative to horizontal landmarks in the vehicle. Ratings include significantly above horizontal, slightly above horizontal, horizontal, slightly below horizontal, and significantly below horizontal.

FEET POSITION: Location of child's feet. Ratings include on floor, almost on floor, hanging over seat, parallel to seat, and on seat.

SITTING HEIGHT: Location of child's head relative to rear seat back. Ratings include entire head below seat, ears below seat, ears along seat, ears above seat, chin above seat, and head almost touching roof.

CLOTHING EFFECT: Effect of clothing on lap and shoulder belt fit. Ratings include no effect on shoulder belt fit, minor effect on shoulder belt fit, major effect on shoulder belt fit, no effect on lap belt fit, minor effect on lap belt fit, and major effect on lap belt fit.

CHEST MARK: Length of belt needed to reach center of child's chest, estimated from markings on the belt.

BELT MARK: Length of belt needed to reach center of child's pelvis, estimated from markings on the belt.

TARGET LOCATION: Position of a target "necklace" worn by the volunteers, relative to the shoulder belt.

After all of the films were evaluated, the data were entered into a spreadsheet for analysis. A volunteer usually had eleven entries: rear seat and three boosters for the Taurus and Sunbird, plus rear seat and two boosters for the Caravan. A total of 1658 observations were obtained in this study. Each observation contains all of the rated data for the particular vehicle/seat/child combination, plus anthropometric data for the child. Several additional variables were derived as well; explanations of all of the variables not previously described are included in Appendix C. The data were converted for input into SAS, which has convenient cross-tabulation and statistical capabilities.

4.4 Vehicle Comparisons: All Observations

The vehicle comparison section uses all observations completed for each vehicle, and includes rear seat, front seat, and booster seat combinations. Most (80%) of the volunteers sat centered within

the seats, regardless of vehicle type. In particular, the contoured rear seat of the Caravan seemed to center the volunteers best. For the off-center positions, inboards outnumbered outboards by a factor of 5. Of the outboard locations, two-thirds occurred with the Taurus. For the inboard positions, 60% occurred with the Sunbird.

The differences in position probably account for some of the differences in shoulder belt fit, which appear in Table 10. The compact car (the Sunbird) had the highest rate of good fit, which is considered centered on the shoulder. Over half (53.2%) were good with the Sunbird, while 38% were good with the Taurus and only 19% were good with the Caravan. Fair fits (slightly off center of the shoulder, both inboard and outboard), were achieved approximately one-third of the time in all three vehicles. Outboard fair and poor fits (too close to or on the arm) happened with only a fraction of the observations in the cars, but not the minivan. Inboard poor fit of the shoulder belt (too close to the neck or face) occurred in 14% of observations for the compact car, 28% of observations for the intermediate car, and 47% of the time with the minivan. Greater z-distance to the shoulder anchor point, plus a steep angle in the x-z plane seem to make shoulder belt fit worse. Because these observations include the vehicle seats alone and with the boosters, this also means that the shoulder belt fit may be less correctable with increasing distance to the shoulder anchor.

Contrastingly, distribution of lap belt fit did not vary with vehicle type. Overall, lap belt scores were 65% good, 21% fair, and 14% poor. Good fits were horizontal over the legs or low on the pelvis, fair were over the pelvis but slightly too high, and poor were over the child's abdomen or approaching the rib cage.

A combined belt fit rating was also developed. If both lap and shoulder belt had good ratings, belt fit was also good. If either one was fair, and the other good, or if both were fair, the observation's belt fit was deemed fair. If either one was poor, the overall fit was regarded as poor. The combined belt fit rankings by vehicle appear in Table 11 and Figure 23. About one-third of the observations for each vehicle had fair fit. The Sunbird had the highest percentage of good and the lowest percentage of poor fit, while the opposite was true for the Caravan. Almost half of the belt fits were poor in the minivan. Belt fit in the Taurus was almost equally distributed among the three ratings.

TABLE 10 -- Shoulder Belt Fit by Vehicle							
Rating	Score	Observations			Percentages		
		T	S	C	T	S	C
In Face	Poor	42	8	47	7.2	1.4	12.1
Against Neck	Poor	119	70	137	20.5	12.6	35.1
On Shoulder; Too Close to Neck	Fair	198	170	131	34.1	30.7	33.6
Centered on Shoulder	Good	219	295	75	37.8	53.2	19.2
Too Close to Arm	Fair	2	10	0	0.3	1.8	0.0
On Arm	Poor	0	1	0	0.0	0.2	0.0
Total		580	554	390	100.0	100.0	100.0

T = Taurus S = Sunbird C = Caravan

TABLE 11 -- Combined Belt Fit by Vehicle						
	Observations			Percentages		
	T	S	C	T	S	C
Good	174	235	70	30.0	42.4	17.9
Fair	205	195	127	35.3	35.2	32.5
Poor	201	124	193	34.7	22.4	49.4
Total	580	554	390	100.0	100.0	100.0

T = Taurus S = Sunbird C = Caravan

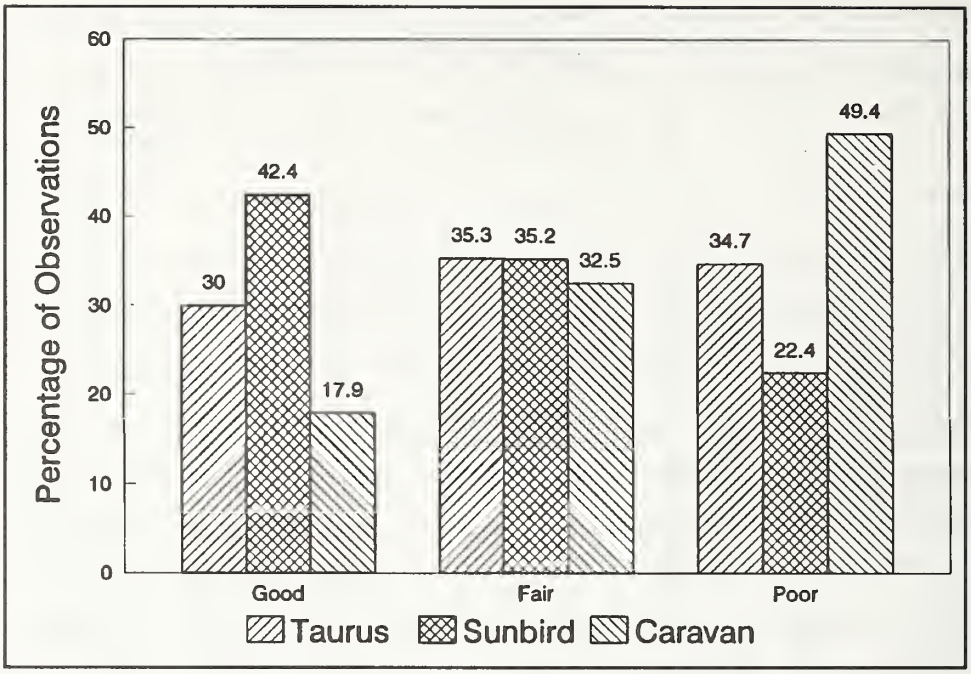

Figure 23 -- Combined belt fit by vehicle

When studying fit within a vehicle, belt fit alone does not necessarily describe the environment. Belt fit does partially depend on posture, but posture should be considered on its own as well. Three main categories were examined in evaluating posture for the volunteers: sitting height, leg angle, and slouch. For sitting height, if the volunteers' ears were along or below the top of the seat back, it was judged acceptable. Any heights higher than that were bad, because the head would not be supported in a rear collision. The basis for including vehicle sitting height as a posture issue is the specification in Federal Motor Vehicle Safety Standard No. 213 that a dummy placed in a booster seat must not have its head center of gravity rise above the seat back. The Sunbird had the highest rate of unacceptable sitting heights, with approximately 25% of the seats placing the volunteers too high relative to the seat back. Only 15% were too high with the Taurus. All of the volunteers had good sitting heights in the Caravan. This corresponds with observations of the seat back designs in the three vehicles. The top of the compact car's rear seat back was horizontal, while the Taurus rear seat back was shaped to form a partial headrest. The captain's chair seat back in the minivan was tall enough for all volunteers to have an acceptable sitting height.

The other two posture considerations must be reviewed with potential for submarining[8]. If the thigh is angled below horizontal, the occupant may slip under the lap belt regardless of how low it rests

over the pelvis. A leg angle significantly above horizontal induces the pelvis to tilt under the lap belt, which also may cause submarining. The best leg angle is horizontal or slightly above horizontal. The degree of slouch also affects the potential for submarining. The more the child slouches down in the seat, the greater potential for the lap belt to slide over the pelvis and load the abdomen.

A combined posture scale was derived to rate these three factors together. If the volunteer sat up straight or almost straight, had an acceptable sitting height, and a horizontal or slightly above horizontal leg angle, he or she received a good posture rating. If the sitting height was unacceptable, the leg angle significantly below horizontal, or the child slouched significantly, a poor rating was given. The remaining combinations received fair ratings. The combined posture results are found in Table 12. The vehicle with the best belt fits (Sunbird) had the worst postures, while the vehicle with the worst belt fits (Caravan) had the best postures. Combining belt fit and posture scores to look at overall fit evened out the ratings between the vehicles. Of the vehicle/seat combinations, 17% were good, 23% were fair, 32% were mediocre, and 29% were poor. Since only 40% of the observations in the survey were good or acceptable, it shows that restraint design with respect to older children could be improved.

TABLE 12 -- Combined Posture by Vehicle

	Observations			Percentages		
	T	S	C	T	S	C
Good	299	205	232	52.0	37.0	59.5
Fair	118	133	118	20.5	24.0	30.3
Poor	158	216	40	27.5	39.0	10.3
Total	575	554	390	100.0	100.0	100.0

4.5 Seat Comparisons: All Observations

The following section reviews the differences in belt fit and postures by seat, regardless of vehicle. The first step is to study the volunteer fit in each booster seat. All of the observations were counted, instead of just one fit per volunteer, because the clothing sometimes affected how the booster seat fit. The differences in seat designs called for the different gradings of fit for each booster. The results on booster seat fit appear in Table 13 and Figure 24. As expected, the Century had the highest

rate of nonfit, because it had the lowest recommended maximum weight. Of the remaining observations with the Century, approximately one-third were a little too snug while the rest appeared to fit comfortably in the seat. About half of the observations with the Volvo had comfortable fit, while 21% were snug. The 23% with tight fit were able to use the Volvo, but the lap belt was not able to be routed as intended. For the Kangaroo, all of the children had shoulders too broad to fit all of the way back into the seat. Their shoulders extended over the side pieces of the seat with varying degrees, as shown in the table. Figures in Appendix D illustrate the different ratings for each booster seat.

TABLE 13 -- Booster Seat Fit

Rating	Score	Observations			Percentages		
		V	K	C	V	K	C
Could Not Fit	Poor	21	22	90	4.8	7.4	20.5
Tight Fit	Poor	101	86		23.2	28.8	
Medium Fit	Fair		131			43.8	
Snug Fit	Fair	91	60	114	20.9	20.1	26.0
Comfortable Fit	Good	222	0	234	51.0	0.0	53.4
Total		435	299	433	100.0	100.0	100.0

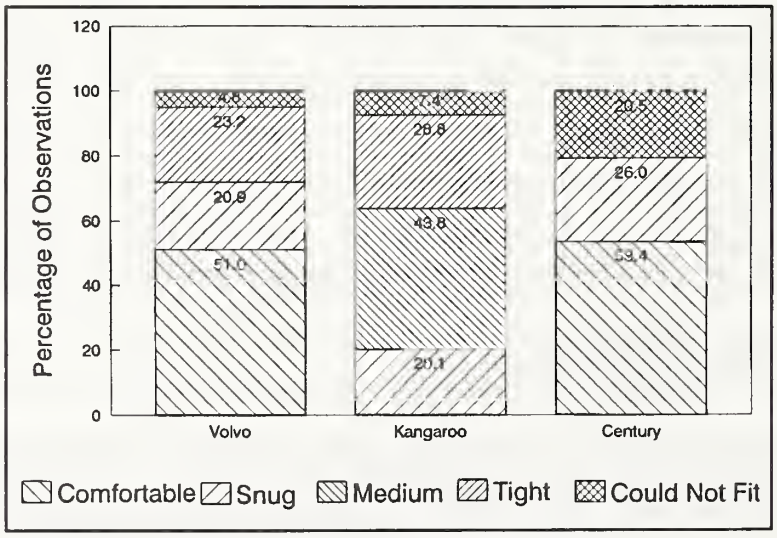

Figure 24 -- Booster seat fit -- all observations

Another look at booster seat fit shows fit rating by weight class for each booster seat, as presented in Tables 14, 15, and 16. The fit for children 33-36 kg (highest recommended weight range for Volvo

and Kangaroo seats) appears in Figure 25. In the highest recommended weight class for the Volvo, 18% had comfortable fit, 62% had snug fit, and 20% had tight fit; all volunteers at or below that weight class were able to sit in the booster. For the Kangaroo in the highest recommended weight class, 3% could not fit at all, 35% had tight fit, 62% had medium fit, and none had snug or comfortable fits. The Kangaroo does not seem to fit the majority of cases in its highest, or even next to highest, recommended weight classes. The Century, although its recommended maximum weight is 6 kg lower than that for the previous two boosters, appears to provide the same degree of fit as the Volvo in the higher weight class. Only 2% could not fit, and 76% had snug fit while 22% had comfortable fit. Children heavier than recommended may be able to comfortably use the Century.

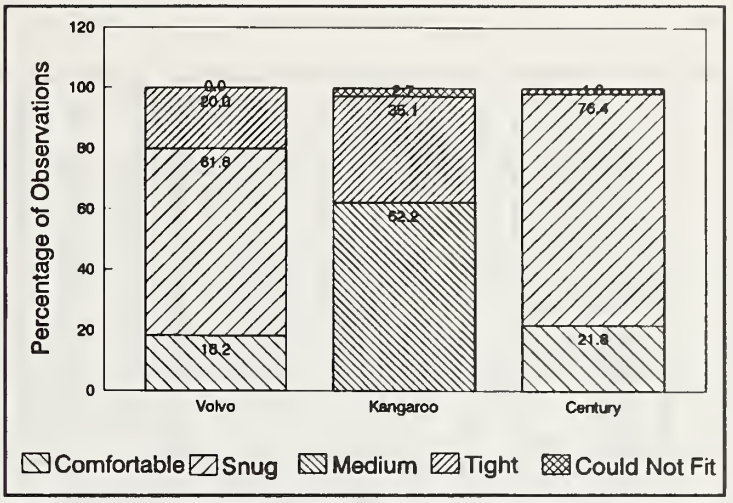

Figure 25 – Booster seat fit of children weighing 33-36 kg

The following discussion compares belt fit and overall fit between seats, regardless of how well the boosters fit. Table 17 and Figure 26 contains shoulder belt fit by seat. For the rear seat alone, only 15.6% of the observations had good fit. In over half the cases (52.5%), the belt rubbed against the neck or face. All of the booster seats drastically cut the occurrence of this shoulder belt fit, down to an average near 17% for all three boosters. Almost half the shoulder belt fits were centered on the shoulder with each booster; about one-third were on the shoulder but too close to the neck. Only a small percentage of observations with the booster seats had the shoulder belt too close to the arm. For the children too large to sit in boosters, the front seat positioned forward gave better belt fit than positioned rearward.

Lap belt fit also drastically improves with the use of booster seats, as shown in Table 18 and Figure 27. Almost 40% of the observations in the rear seat alone had lap belt fits high on the abdomen. The Volvo positioned the lap belt low over the legs or pelvis 93% of the time. The other two boosters placed the lap belt low just over 70% of the time. Both of the front seat positions had adequate lap belt fits most of the time.

TABLE 14 -- Booster Seat Fit by Weight Class for Volvo														
	Observations							Percentages						
Weight (kg)	< 23	24-27	28-32	33-36	37-41	42-50	51 +	< 23	24-27	28-32	33-36	37-41	42-50	51 +
Could Not Fit	0	0	0	0	0	2	16	0.0	0.0	0.0	0.0	0.0	4.4	54.3
Tight Fit	0	0	6	11	27	11	16	0.0	0.0	5.4	20.0	58.7	91.1	45.7
Snug Fit	0	8	29	34	18	2	0	0.0	9.5	25.9	61.8	39.1	4.4	0.0
Comfortable Fit	58	46	77	10	1	0	0	100.0	90.5	68.8	18.2	21.7	0.0	0.0
Total	58	84	112	55	46	45	35	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 15 -- Booster Seat Fit by Weight Class for Kangaroo														
	Observations							Percentages						
Weight (kg)	< 23	24-27	28-32	33-36	37-41	42-50	51 +	< 23	24-27	28-32	33-36	37-41	42-50	51 +
Could Not Fit	0	0	1	1	0	5	16	0.0	0.0	1.3	2.7	3.3	14.1	60.9
Tight Fit	1	0	18	11	23	25	0	2.4	6.7	14.1	39.1	76.7	80.6	39.1
Medium Fit	0	34	59	23	6	0	0	22.0	55.9	75.6	62.2	20.0	3.2	0.0
Snug Fit	31	22	7	0	6	0	0	75.6	37.3	0.0	0.0	0.0	0.0	0.0
Comfortable Fit	0	0	6	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	41	59	78	37	37	31	23	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 16 -- Booster Seat Fit by Weight Class for Century

	Observations							Percentages						
Weight (kg)	< 23	24-27	28-32	33-36	37-41	42-50	51 +	< 23	24-27	28-32	33-36	37-41	42-50	51 +
Could Not Fit	0	0	2	1	16	39	32	0	0	1.7	1.8	34.8	86.7	91.4
Snug Fit	1	5	29	12	29	6	3	1.8	6.0	24.3	76.4	63.0	13.3	8.6
Comfortable Fit	57	79	85	12	1	6	0	98.3	94.0	73.9	21.8	21.7	0.0	0.0
Total	58	84	115	55	46	45	35	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 17 -- Shoulder Belt Fit by Seat

Rating	Score	Observations						Percentages					
		R	V	K	C	FF	FR	R	V	K	C	FF	FR
In face	Poor	79	6	2	7	0	3	18.1	1.4	0.4	2.2	0.0	15.8
Against neck	Poor	149	68	42	55	8	3	34.1	16.3	15.8	15.8	34.6	15.8
On shoulder; too close to neck	Fair	139	131	89	127	8	5	31.8	31.3	32.1	36.5	30.8	26.3
Centered on shoulder	Good	68	209	137	158	9	8	15.6	51.1	49.5	45.4	34.6	42.1
To close to arm	Fair	2	3	6	1	0	0	0.5	7.2	2.2	0.3	0.0	0.0
Over arm	Poor	0	6	1	6	0	0	0.0	0.0	0.4	0.0	0.0	0.0
Total		437	417	277	348	26	19	100.0	100.0	100.0	100.0	100.0	100.0

R = Rear Seat FF = Front Seat, Forward FR = Front Seat, Rearward V = Volvo K = Kangaroo C = Century

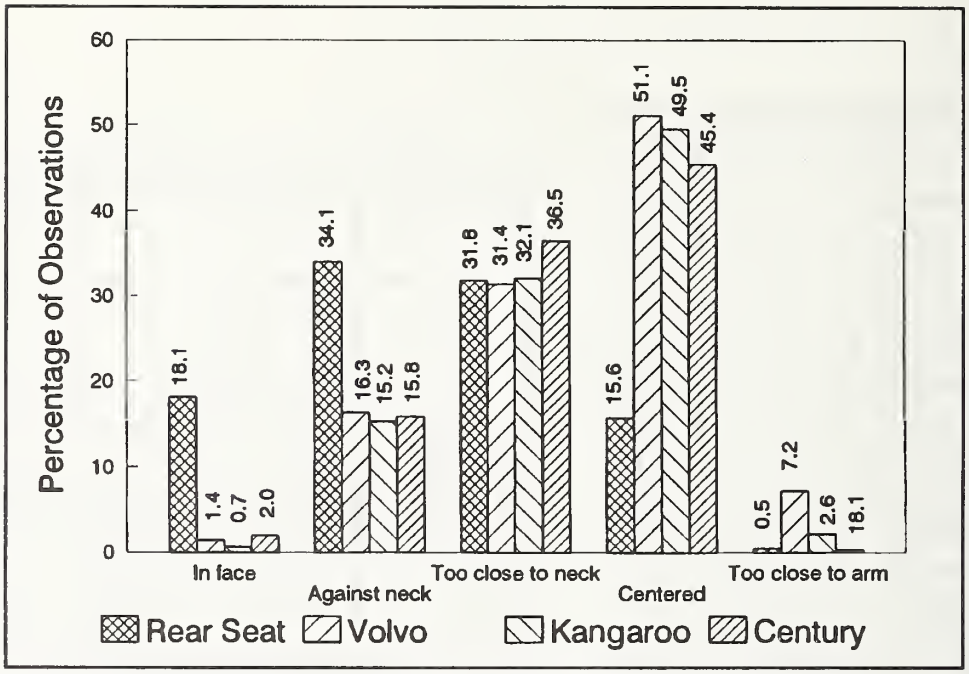

Figure 26 -- Shoulder belt fit for rear seat alone and booster seats

TABLE 18 -- Lap Belt Fit by Seat

Rating	Score	Observations						Percentages					
		R	V	K	C	FF	FR	R	V	K	C	FF	FR
Flat over Legs	Good	3	300	35	300	1	3	0.7	71.9	12.6	16.1	3.8	15.8
Low over Pelvis	Good	106	200	181	200	9	8	24.3	21.3	65.3	57.5	34.6	42.1
Pelvis	Fair	160	22	49	70	12	5	36.6	5.3	17.7	20.1	46.2	26.3
Abdomen	Poor	123	4	11	20	4	4	28.1	1.4	4.0	5.7	15.4	15.8
Near Ribcage	Poor	45	0	1	2	0	0	10.3	0.0	0.4	0.6	0.0	0.0
Total		437	417	277	348	26	19	100.0	100.0	100.0	100.0	100.0	100.0

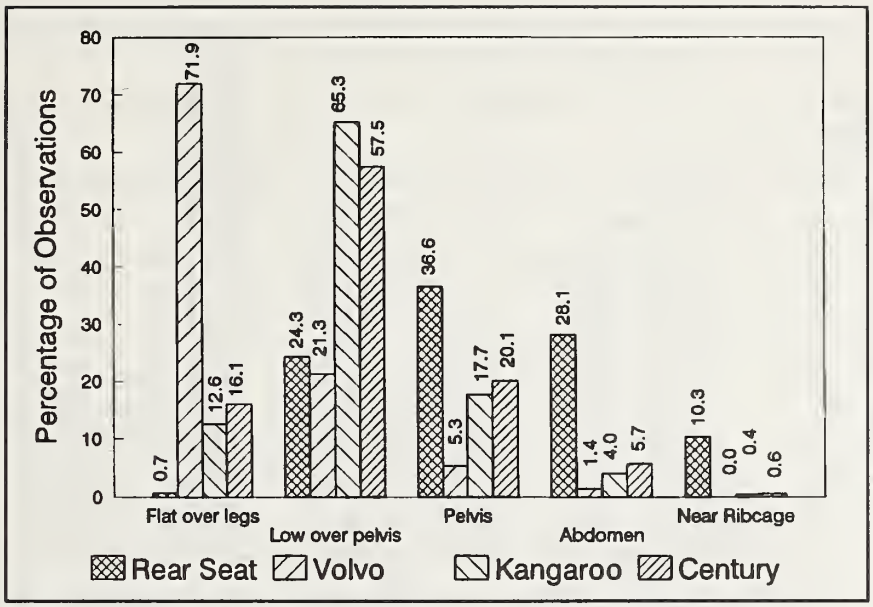

Figure 27 -- Lap belt fit for rear seat and booster seats

Looking at the combined belt fit in Table 19 and Figure 28, the rear seat alone has good or fair fit only 34.1% of the time. The percentage of good/fair fit increases to around 80% for all three booster seats. The front seat positions had slightly better combined belt fits than the rear seat. The combined posture ratings by seat appear in Table 20. The rear seat postures are almost evenly split between the good, fair, and poor classes. The Volvo has the best posture, allowing only 17% to be considered poor. The Century also does well, with only 14% poor posture, although the mix of good vs. fair is not quite as favorable as with the Volvo. Contrary to the other boosters, the Kangaroo does not generally improve posture. Its high cushion depth raises more volunteers above an acceptable sitting height. The soft foam of the seat does not the support the legs as well, which causes more thigh angles to fall below horizontal. For the front seat positions, the posture is generally good.

TABLE 19 -- Combined Belt Fit by Seat

	Observations						Percentages					
Fit	R	V	K	C	FF	FR	R	V	K	C	FF	FR
Good	30	201	112	129	3	4	6.9	48.2	40.4	37.1	11.5	21.1
Fair	119	137	111	143	10	7	27.2	32.9	40.1	41.1	38.5	36.8
Poor	288	79	54	76	13	8	65.9	18.9	19.5	21.8	50.0	42.1
Total	437	417	277	348	26	19	100.0	100.0	100.0	100.0	100.0	100.0

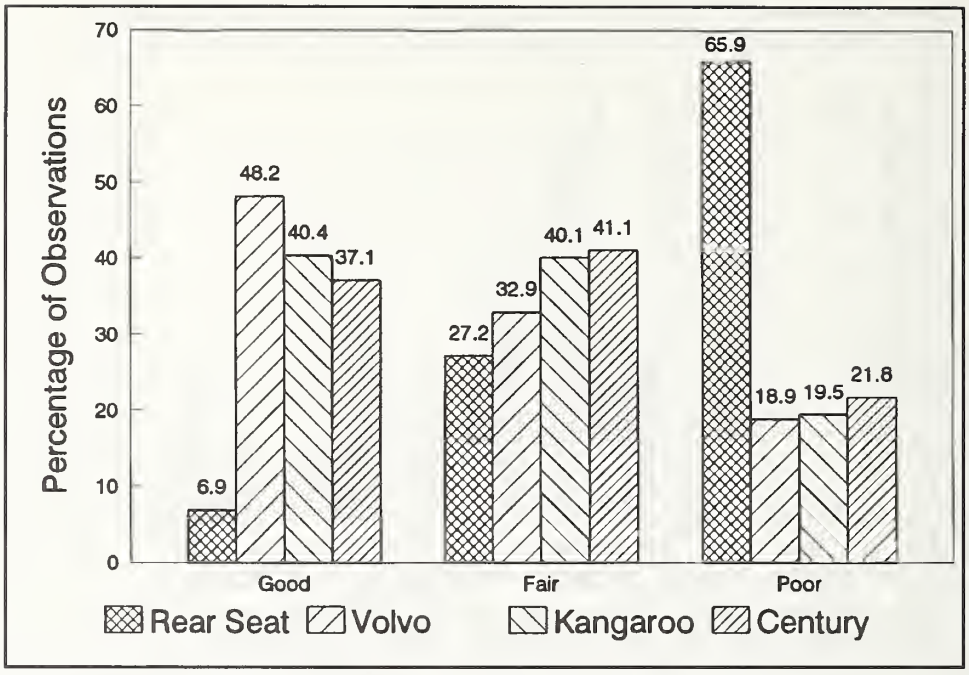

Figure 28 -- Combined belt fit for rear seats and booster seats

TABLE 20 -- Combined Posture by Seat

	Observations						Percentages					
Fit	R	V	K	C	FF	FR	R	V	K	C	FF	FR
Good	154	279	70	195	21	17	35.4	67.2	25.2	56.2	80.8	89.5
Fair	154	67	36	105	5	2	35.4	16.1	13.0	30.3	19.3	10.5
Poor	127	69	171	47	0	0	29.2	16.6	61.7	13.5	0.0	0.0
Total	435	415	277	347	26	19	100.0	100.0	100.0	100.0	100.0	100.0

The final step in the seat comparison analysis is to look at the overall fit, shown in Table 21. The rear seat allows reasonable fit only 19% of the time. The Volvo and Century offer significant increases in protection by having good or fair fit in 61% and 54% of the observations. Some of the fair and poor fits for these two boosters result from the volunteer being too large to sit properly in the booster. The Kangaroo improves the fit slightly over the rear seat, but neglects the needs of most of the volunteers.

TABLE 21 -- Overall Fit by Seat												
	Observations						Percentages					
	R	V	K	C	FF	FR	R	V	K	C	FF	FR
Good	20	128	21	82	1	3	4.6	30.8	7.6	23.6	3.8	21.1
Fair	63	125	34	106	12	8	14.5	30.1	12.3	30.5	46.2	31.6
Mediocre	124	119	120	101	10	8	28.5	28.7	43.3	29.1	38.5	42.1
Poor	228	43	102	58	3	1	52.4	10.4	36.8	16.7	11.5	5.3
Total	435	415	277	347	26	19	100.0	100.0	100.0	100.0	100.0	100.0

4.6 Clothing Effect

Since the vehicles were tested consecutively, and the survey was conducted between March and May in central Ohio, the effect of coats varied with each vehicle, as seen in Table 22. The intermediate-sized Taurus had by far the greatest effect from coats on both shoulder and lap belt fit. Bulky coats would generally make lap belt fit worse by forcing the belt higher up the volunteer's abdomen. However, shoulder belt fit usually improved, because a bulky collar would push the shoulder belt toward the center of the shoulder. Photos that illustrate major and minor effects of clothing on belt fit are located in Figures 29 and 30.

To quantify the changes resulting from different clothing, the observations were split into three groups and compared to the distributions generated for all of the observations. The three groups were no clothing effect (63% of observations), minor clothing effect (28%), and major clothing effect (9%). Discarding the observations wearing coats was suggested, because coats add a complicating factor to the fit issue. However, some coats had an effect, while others did not, depending on how bulky they were and how they happened to be placed within the seat belt. In addition, some of the clothing effect resulted from just a bulky sweatshirt or sweater. Another suggestion was to delete the observations with any clothing effect at all. However, this would reduce the number of observations by over one-third. It also seemed to contradict the original goal of studying fit on real kids, because sometimes real kids

TABLE 22 – Effect of Clothing on Belt Fit for each Vehicle							
Belt	Effect	Observations			Percentages		
		T	S	C	T	S	C
Shoulder	Major	11	3	0	1.9	0.1	0.0
	Minor	276	79	19	47.6	14.3	4.9
	None	293	472	371	50.5	85.2	95.1
	Total	580	554	390	100.0	100.0	100.0
Lap	Major	105	22	11	18.2	4.0	2.8
	Minor	197	78	48	34.1	14.1	12.3
	None	276	454	331	47.8	81.9	84.9
	Total	578	554	390	100.0	100.0	100.0

Figure 29 – Major clothing affect on lap and shoulder belt

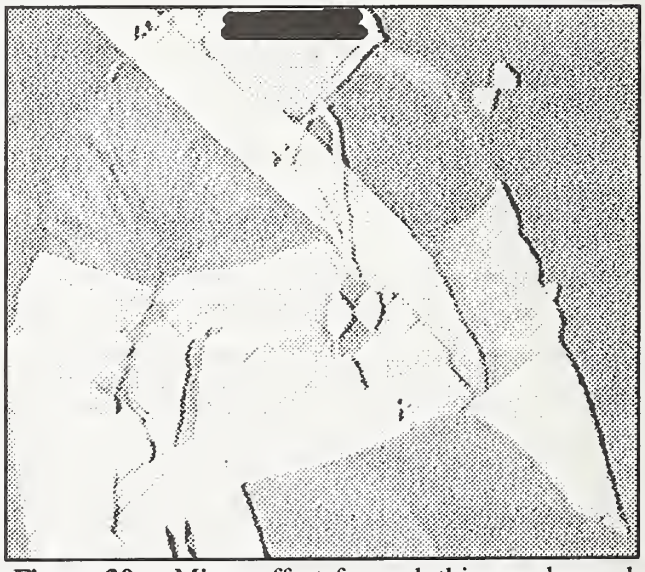

Figure 30 – Minor effect from clothing on lap and shoulder belt fit

wear coats or bulky clothing, and should therefore be included. As a check to see what would happen if observations with minor or major clothing effect were discarded, the lap fit and shoulder fit by vehicle were compared, as shown in Figures 31 and 32. The plots show the difference between all observations and those without any clothing effect. For the shoulder belt, the differences between the two groups are minimal, and none are statistically significant. For the lap belt, the differences are slightly larger, but the only statistically significant distribution difference is with the Taurus. The observations with clothing effect were therefore kept, but fit variables that statistically differed because of clothing were noted.

The distributions of five fit variables (shoulder fit, lap fit, combined belt fit, posture, and overall fit) were reviewed for the three groups, and compared to the distributions for the whole set of data. Table 23 contains the baseline and differing distributions for the statistically significant cases. All of the distributions for the minor effect group were the same as for the whole group. For the no clothing effect group, the distributions were the same except for lap belt fit. For the Taurus, lap belt fit improved when isolating the group without coats. The same happened for the Volvo, Kangaroo, and Century boosters. As expected, most of the differences occurred with the major clothing effect group. Lap belt fit became much worse for the Volvo, Kangaroo, Century, and rear seat alone, as did the combined belt fit scores. For the Kangaroo and Century, the overall fit was not as good for the major clothing effect group.

4.7 Rear Seats vs. Booster Seats by Vehicle

The original analysis compared fit between vehicles, regardless of seat, and fit between seats, regardless of vehicle. The following compares fit for rear seats and boosters in each vehicle.

Table 24 shows that the rear seat and booster seats in the Sunbird both provide the best shoulder fit. The Taurus is next best, followed by the Caravan. Although the booster seats in each vehicle improve shoulder belt fit, the boosters in the Caravan still have about one-third of the observations with poor fit. As shown in Table 25, lap belt fit in the rear seat is almost exactly the same across the vehicles. The same is true for the booster seats; they improve lap belt fit in all three vehicles. Table 26 shows the combined belt fits by vehicle and seat. The Sunbird rear seat is the best among the three vehicles, although over half still had poor fit. The Taurus rear seat placed next, with two-thirds of the entries having poor combined belt fit. The Caravan rear seat had three-quarters of the belt fit ranked as poor. All of the booster seats showed improvement in each vehicle, although the best-to-worst order was the same as for the rear seat alone.

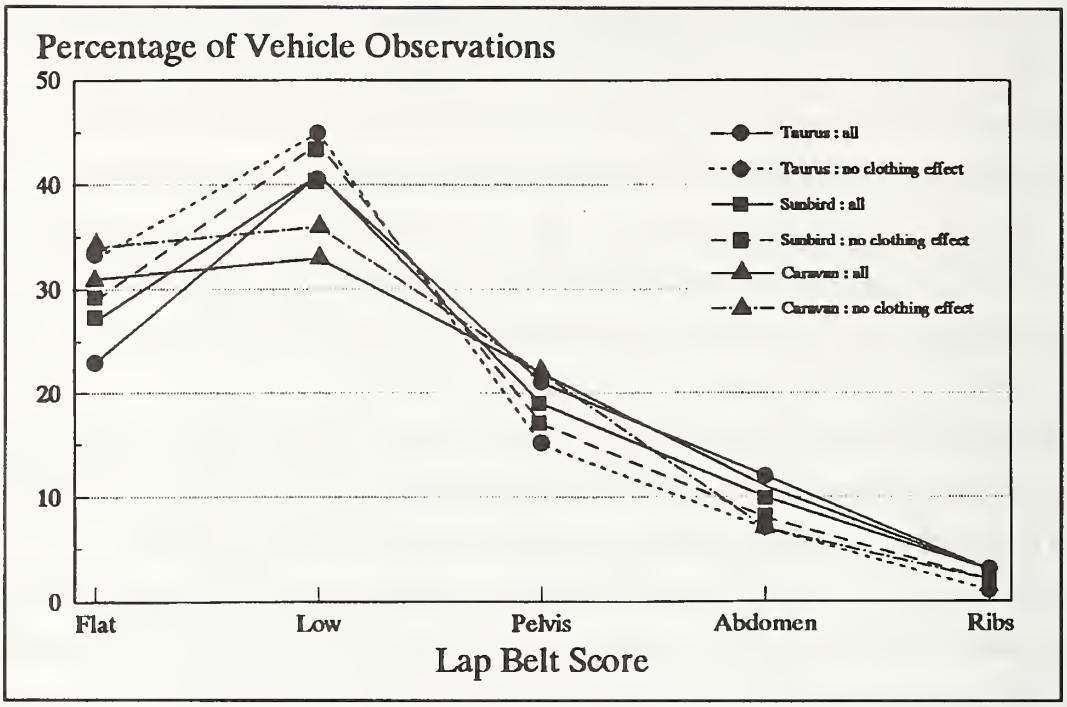

Figure 31 -- For each vehicle, the change in lap belt fit between all observations and those without any clothing effect

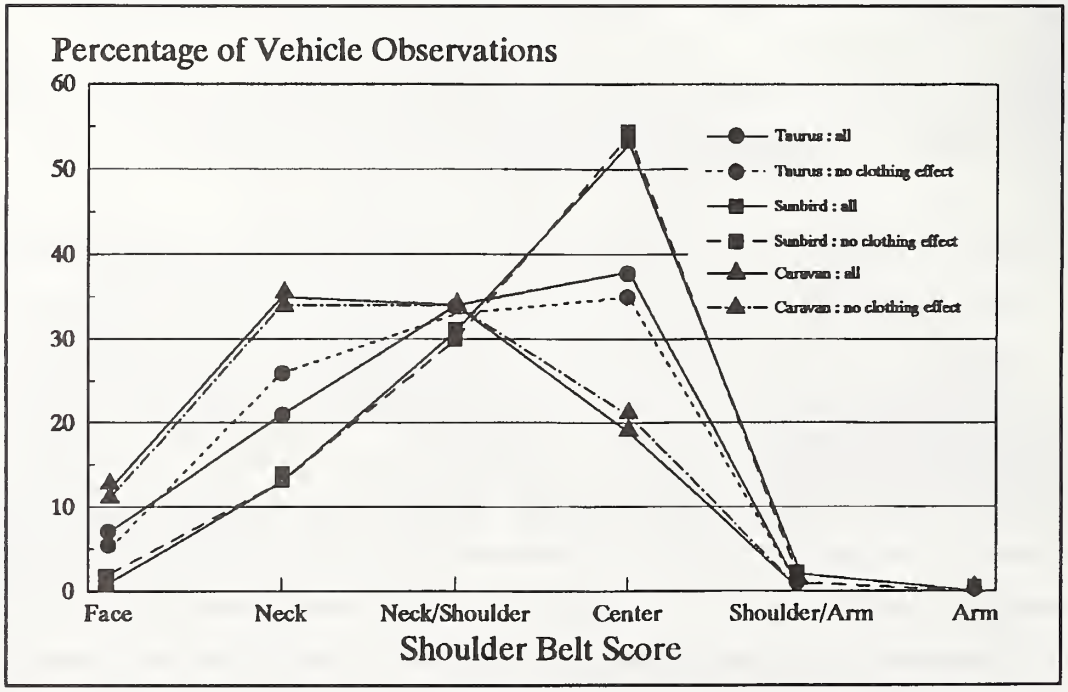

Figure 32 -- For each vehicle, the change in shoulder belt fit between all observations and those without clothing effect

TABLE 23 – Statistically Significant Differences from Clothing Effect								
Variable	Vehicle /Seat	Group	N	Percentages at Each Rating				
				Flat Over Legs	Low Over Pelvis	Pelvis	Abdomen	Ribcage
Lapfit	Taurus	All	580	23	41	21	12	3
		None	203	33	45	15	7	1
	Volvo	All	417	72	21	5	4	0
		None	289	80	16	3	6	0
		Major	27	15	37	33	15	0
	Kangaroo	All	277	13	65	12	4	0
		None	155	13	74	12	1	0
		Major	30	3	13	57	23	3
	Century	All	348	16	57	20	6	1
		None	212	10	66	15	0	0
		Major	39	3	21	41	31	5
	Rear	All	437	1	24	37	28	10
		Major	45	0	0	20	40	36
Beltfit	Vehicle/ Seat	Group	N	Good	Fair	Poor		
	Rear	All	437	7	27	66		
		Major	45	3	16	84		
	Volvo	All	417	48	33	19		
		Major	27	26	37	37		
	Kangaroo	All	277	30	30	19		
		Major	30	3	60	37		
	Century	All	348	37	41	22		
		Major	30	10	44	46		
Combined Fit	Vehicle/ Seat	Group	N	Good	Fair	Mediocre	Poor	
	Kangaroo	All	277	8	12	33	37	
		Major	30	0	13	27	60	
	Century	All	347	24	41	29	17	
		Major	39	5	26	31	38	

All = all observations None = observations without clothing effect Major = observations with major clothing effect

TABLE 24 – Shoulder Belt Fit by Vehicle							
Rating		Rear Seat Percentages			Booster Seat Percentages		
		T	S	C	T	S	C
In Face	Poor	22	4	29	1	1	3
Against Neck	Poor	34	26	43	15	7	31
On Shoulder; Too Close to Neck	Fair	29	42	24	36	27	39
Centered on Shoulder	Good	15	27	4	47	63	27
Too Close to Arm	Fair	0	1	0	0	2	0
Number of Observations		153	145	439	401	397	244

TABLE 25 – Rear Seat vs. Booster Seat Lap Belt Fit by Vehicle							
Rating	Score	Rear Seat Percentages			Booster Seat Percentages		
		T	S	C	T	S	C
Flat over Legs	Good	1	1	0	31	37	38
Low over Pelvis	Good	24	23	25	47	47	38
Pelvis	Fair	33	34	42	16	13	10
Abdomen	Poor	31	29	24	5	3	3
Near Ribcage	Poor	10	12	8	0	0	0
Number of Observations		153	145	139	401	397	244

TABLE 26 – Combined Belt Fit by Seat						
	Rear Seat Percentages			Booster Seat Percentages		
Fit	T	S	C	T	S	C
Good	8	9	3	40	55	26
Fair	22	37	22	40	34	38
Poor	69	54	75	20	11	36
Number of Observations	153	145	139	401	397	244

Table 27 contains the combined posture by seat ratings. For the rear seat alone, the Taurus and Sunbird had almost identical distributions of one-third good, one-third fair, and one-third poor. The Caravan rear seat had better combined posture ratings, with a two-fiths, two-fifths, one-fifth distribution among good, fair, and poor. The booster seats improved posture in the Taurus and Caravan, but it became worse in the Sunbird. A possible reason is the low rear seat back in the Sunbird, which would cause more children to have their heads too high while seated in a booster.

TABLE 27 – Combined Posture by Seat

	Rear Seat Percentages			Booster Seat Percentages		
Fit	T	S	C	T	S	C
Good	35	32	40	56	38	70
Fair	32	34	40	17	20	25
Poor	32	34	21	27	42	5
Number of Observations	151	145	139	398	397	244

In Table 28, the overall fit for the rear seat in each vehicle is similar, with just over half poor. The distributions with the booster seats are similar as well, with the boosters showing improvement in all vehicles. The Caravan was slightly better. An explanation for this may be that the Kangaroo was not used with this vehicle, and the worst postures usually occurred with this booster seat.

TABLE 28 – Overall Fit by Seat

	Rear Seat Percentages			Booster Seat Percentages		
	T	S	C	T	S	C
Good	5	6	3	23	22	21
Fair	13	17	13	26	21	32
Mediocre	27	26	32	31	35	32
Poor	54	51	52	20	22	15
Number of Observations	151	145	139	398	397	244

4.8 Effect of Vehicle Sitting Height on Posture

As discussed previously, the combined posture score includes slouch, leg angle, and sitting height with respect to the seat back. The sitting height was included because FMVSS No. 213 specifies that for a child dummy in a child restraint, the dummy's head center of gravity must not rise above the rear seat back. In addition, the booster manufacturers cautioned against using the boosters if the child's head was too high. However, some of the larger children were receiving poor posture scores only because their heads rose above the seat back, particularly in the Sunbird. The children affected by the original definition of posture are actually the size of small adults, and the adult dummies have no limit on sitting height with respect to the seat. In addition, for older children, the sitting height limit may not be as important because their heads are not as great a proportion of their total body weight as compared to smaller children. To see how much sitting height affects posture and the overall combined fit, the scores were refigured without including the sitting height criteria. The results that appear in Table 29 show that 12% of the entries had poor posture because of sitting height. For posture, 6% shift from poor to fair while the remaining 6% shift from poor to good. For the combined fit, about 4 or 5% shift from the mediocre/poor categories to the good/fair ratings. Excluding sitting height from posture makes the posture and combined fit scores slightly better, but not by much.

TABLE 29 -- Effect of Vehicle Sitting Height

Variable	Rating	Include Sitting Height	Exclude Sitting Height
Posture	Good	48%	54%
	Fair	24%	30%
	Poor	27%	15%
Combined Fit	Good	17%	21%
	Fair	23%	27%
	Mediocre	32%	27%
	Poor	29%	24%

4.9 Slouch Factor

The data from this survey shows that booster seats improve belt fit and posture. When conducting the survey, a trend appeared that partly explains how booster seats accomplish this. The volunteers were always asked to sit up as straight as possible. They generally did some of the time. After surveying a number of children, the reason why some of them weren't sitting up straight became apparent. Figure 33 illustrates the phenomena termed the "slouch factor". When older children sit up straight, the widest part of their calves rests on the edge of the seat, as shown in Figure 33a. This puts pressure on their legs and causes discomfort. Instead of sitting like this, they will scoot forward to let their legs hang more comfortably, as shown in 33b. This makes them slouch, often causing the lap belt to slide up onto their abdomens and their faces to become closer to the shoulder belt. One of the reasons why booster seats work is that they discourage this slouching. As Figure 33c illustrates, the booster lifts them up so their legs rest more comfortably on the edge of the seat. Very small children do not have this problem (Figure 33d) because they can comfortably rest their entire legs on the seat; neither do adults (Figure 33e) because their legs are long enough to reach the floor comfortably. Figures 34 and 35 show a nine-year-old child sitting in a generic automotive seat in upright and slouched positions. The child was uncomfortable when asked to sit upright, because it put pressure on the backs of her lower legs. This posture, which is normal for younger child dummies, is not one that a real older child would be able to sit in.

4.10. Child Size vs. Fit

The preceding analysis of older children showed that in general, booster seats improved fit. However, some children had good fit in the rear seat alone, and with the booster. Contrary to these children, some had poor fit in both the rear seat alone and in the boosters. Others had different combinations for both rear seats and boosters. The following section tries to define the anthropometric characteristics of the children that indicate the minimum size necessary for good fit with a three-point belt, and the maximum size for using or benefitting from booster seats.

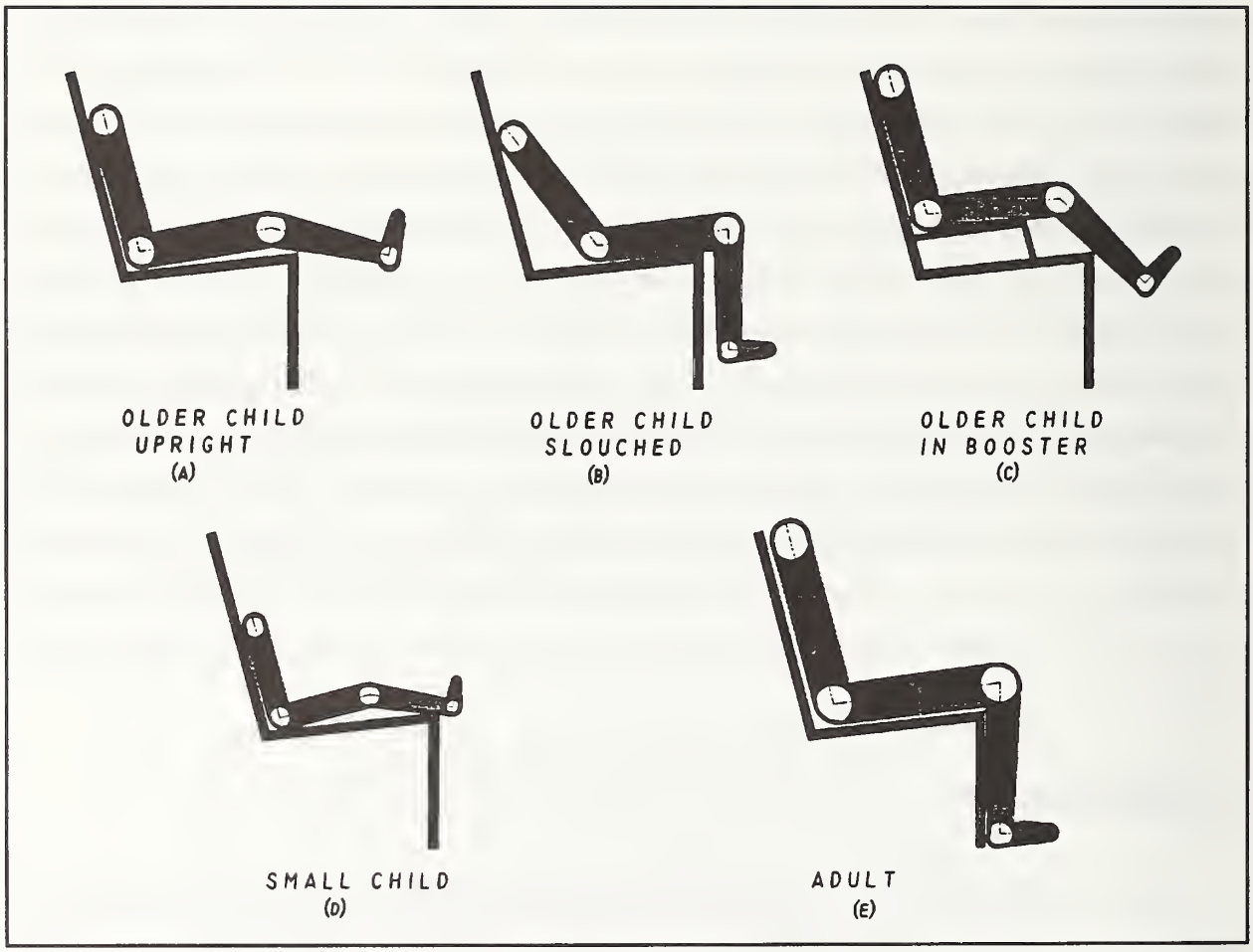

Figure 33 – Illustration of "slouch factor"

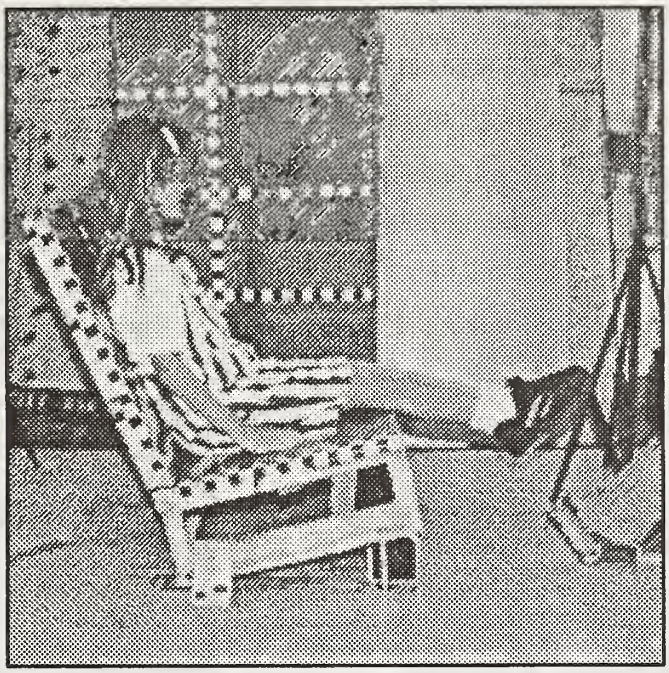

Figure 34 – Child sitting upright with uncomfortable leg position

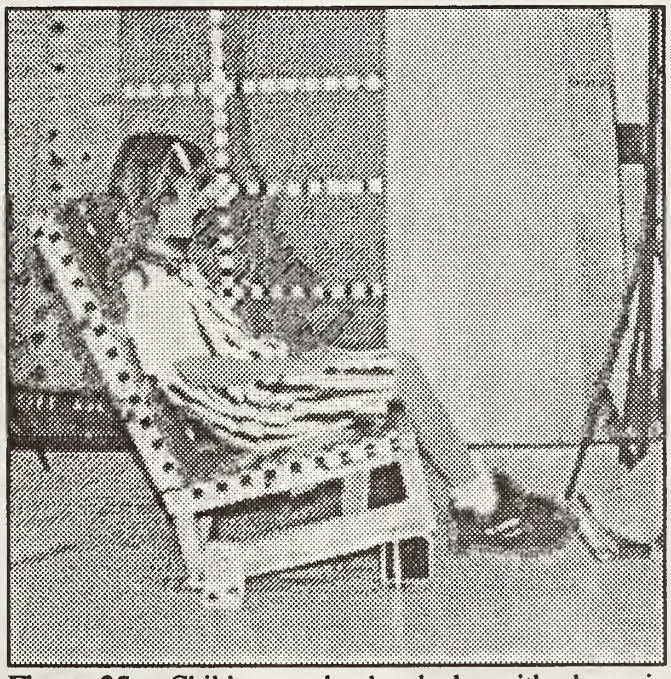

Figure 35 – Child seated slouched, with legs in comfortable position.

Booster seat manufacturers primarily define the sizes of children that could use a particular seat by setting weight ranges, and sometimes height ranges. The two children pictured in Figures 36 and 37 show that using weight alone is an oversimplification. Both of these volunteers weigh 36 kg, but have a height difference of 15 cm, and a sitting height difference of 7.6 cm. The shorter child had 9 out of 11 poor combined belt fits, while the taller girl had only 1 out of 10 poor belt fits. In addition, the shorter girl had more uncomfortable fits in the boosters than the taller one. Weight, height, and sitting height must all be considered when looking at relationships between size and belt fit.

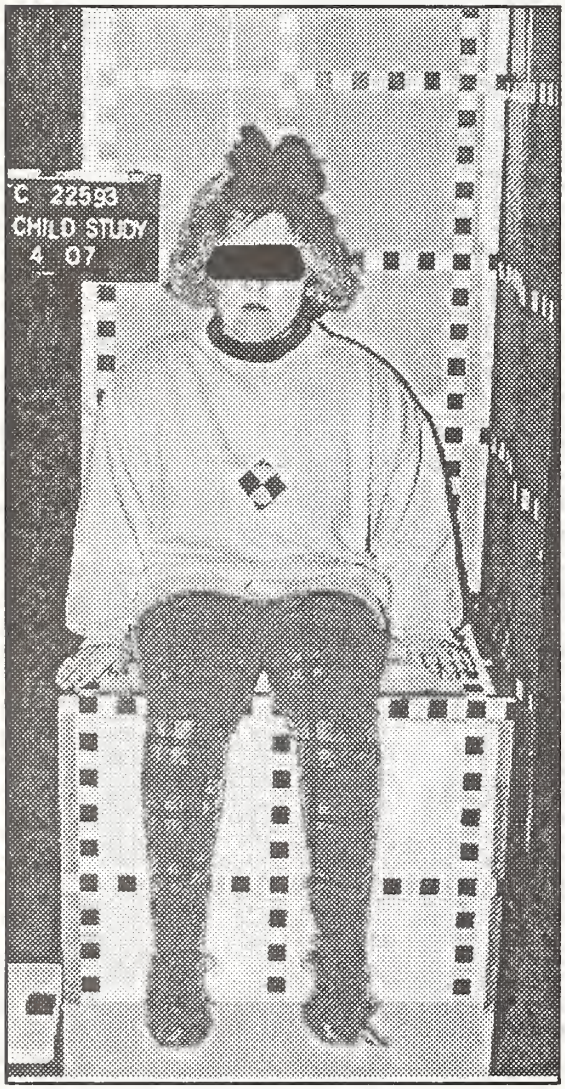

Figure 36 – Child who weighs 36 kg, stands 128 cm tall, and had 9/11 poor belt fits

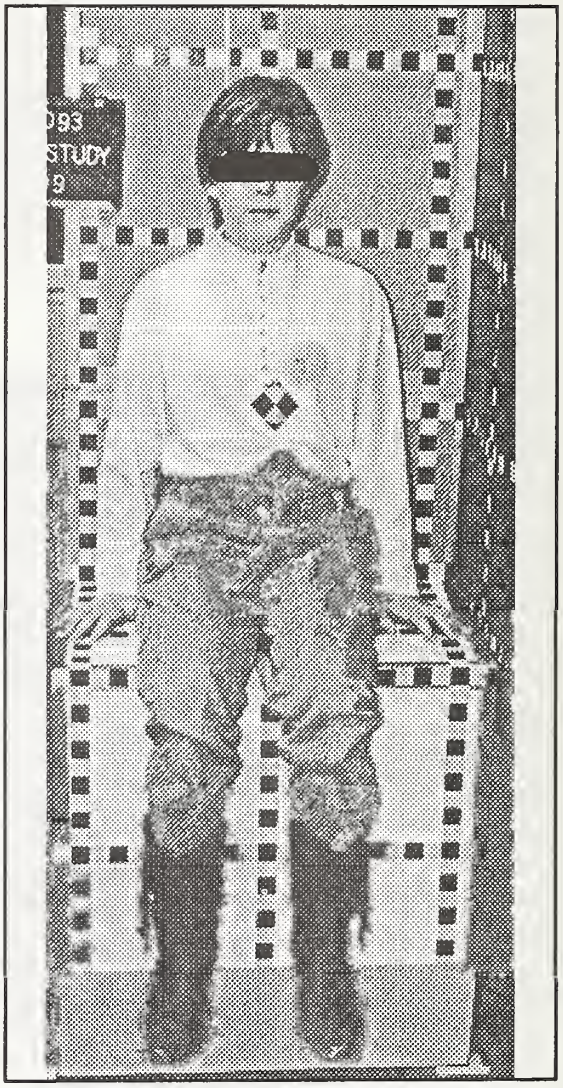

Figure 37 – Child who weighs 36 kg, stands 145 cm tall, and has 2/9 poor belt fits.

A first step in this analysis was to look at the relationship between sitting height and belt fit. Figure 38 shows the percentage of good and poor lap belt fits for the rear seats and booster seats separately. The boosters generally have the same rates of good and poor lap belt fit regardless of sitting height. Over 80% are good, and fewer than 10% are poor for every sitting height. This indicates that most of the children seated in boosters had good lap belt fit regardless of sitting height.

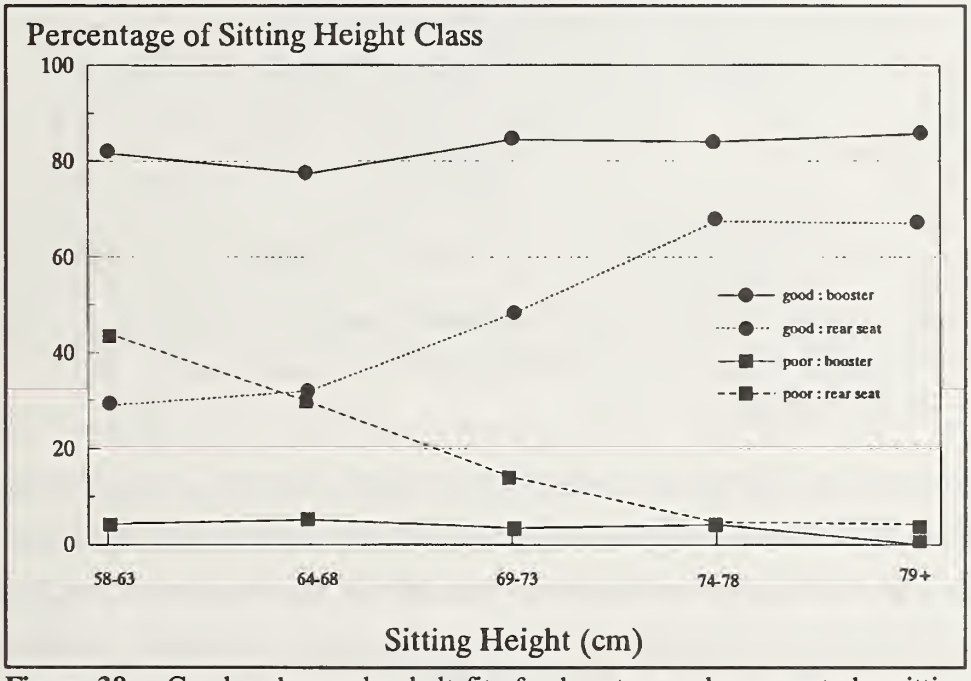

Figure 38 -- Good and poor lap belt fits for boosters and rear seats by sitting height

The rear seat observations are much different. The poor lap belt fits do not fall below 10% until a sitting height of 74-78 cm is reached; the taller sitting height classes have about 70% good lap belt fit. For the 69-73 cm sitting height class, the poor lap belt fits are about 15%, but the good lap belt fits are only about 50%, indicating that children with these sitting heights can probably not use the belt alone and get a good lap belt fit.

For the shoulder belt fit shown in Figure 39, the differences between rear seat and booster seat for shoulder belt are not as large. For almost every sitting height class, the percentage good with the booster is higher than the percentage good for the rear seat, and the percentage poor with the booster is less than the percentage poor with the rear seat. Until the 74-78 cm sitting height class is reached, the poor percentages are much higher than the good percentages. At that sitting height and above, the levels of good and poor are comparable.

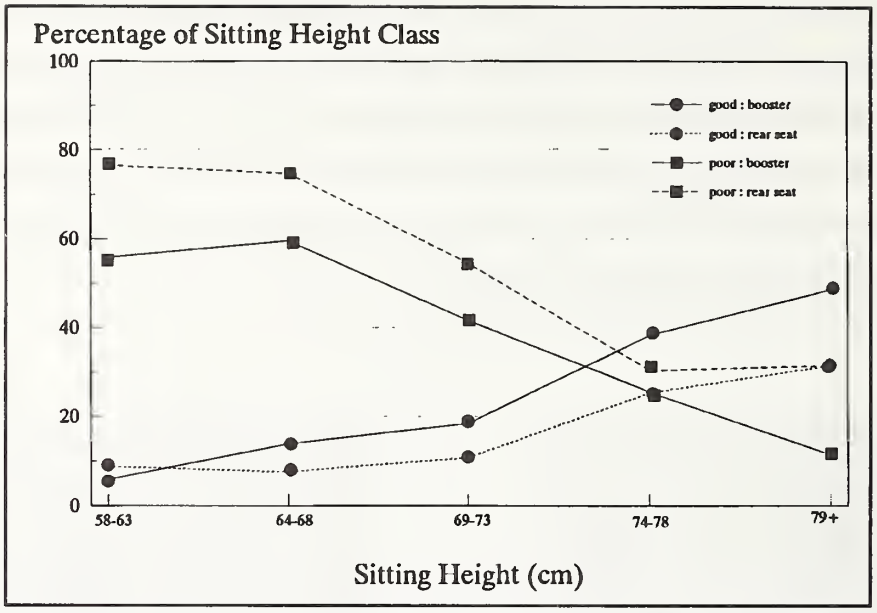

Figure 39 – Good and poor shoulder belt fits for boosters and rear seats by sitting height

When considering both lap and shoulder belt fit, children with sitting heights 73 cm and below cannot use three-point belts effectively, while those above 73 cm can do so some of the time. It appears that all sitting heights can benefit from boosters. However, the observations here include children who benefitted from the booster, even though the booster fit too tightly or improperly. Children who benefit from boosters are not the same as those who fit in boosters.

To look at size vs. fit a different way, the children were reviewed according to height/weight categories and combined belt fit. To try to determine the smallest-sized child that can effectively use a three-point belt, the three rear seat entries for each volunteer were reviewed. If they had poor combined belt fit two or three times in the rear seat, they were considered poor. If they had only one poor score, they were considered fair. If they had no poor scores they were considered good. Then, the height/weight class chart was used to map out how many children in each particular height/weight class had overall poor combined belt fit. The results appear in Table 30. Each cell contains the number of children with overall poor belt fit, and the number of children in that particular height/weight class. The boxes are shaded where the majority of the height/weight class was considered poor. A height of 148 cm seems to be the threshold above which poor belt fit is not a problem. A weight of 36 kg might be considered a threshold if the chubbiest children (the shortest for a given weight) are ignored. The table does show that the poor belt fits occur most often with the chubbiest children.

TABLE 30 -- Children with Overall Poor Combined Belt Fit in Rear Seat Alone							
Weight (kg)	Height (cm)						
	112-117	118-124	125-132	133-140	141-147	148-155	156-168
< 23	5/5	12/13	2/3	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
24-27	\\\\\\\\\	5/6	14/18	4/6	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
28-32	1/1	1/1	9/9	11/17	6/11	\\\\\\\\\	\\\\\\\\\
33-36	\\\\\\\\\	\\\\\\\\\\	2/2	7/7	3/8	1/2	\\\\\\\\\
37-41	\\\\\\\\\	\\\\\\\\\\	2/2	1/3	0/4	2/7	\\\\\\\\\
42-50	\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	1/2	4/7	3/7	0/1
51 +	\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	2/2	2/5	0/6

Table 31 contains the number of children whose overall combined belt fit was better with booster seats than with belts alone. This table therefore includes those who benefit from boosters, though they may not necessarily fit in the boosters very well. In a manner similar to that used with the three rear seat entries, if 6 or more out of 8 belt fits with the booster were good, the overall booster score was good; if fewer than 3 out of 8 belt fits with the booster were good, the overall booster score was poor; the remaining combinations were considered fair. The shaded squares indicate that a majority of children in that particular height/weight class had improved fit with a booster. Children who had the same fit in belts and boosters (good/good, fair/fair, and poor/poor) are not included. The large number of shaded squares indicates that boosters improve belt fit for almost all height/weight combinations. The smallest children did not benefit from belt-positioning boosters; the results were poor with and without the boosters because of their small sizes.

As mentioned previously, children who benefit from boosters and those who fit in boosters are not necessarily the same children. Table 32 tries to illustrate the difference. This table includes children who had overall good or fair combined belt fits with the boosters, and had comfortable or snug fits in the boosters. Few children over 36 kg were able to fit well in the boosters, so a threshold is evident. However, since the previous table indicates that children over 36 kg could benefit from boosters, it may be advantageous for booster seat manufacturers to build wider seats that could accommodate and help these heavier children.

TABLE 31 – Combined Belt Fit with Boosters Better than Combined Belt Fit in Rear Seat							
Weight (kg)	Height (cm)						
	112-117	118-124	125-132	133-140	141-147	148-155	156-168
< 23	1/5	11/13	3/3	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
24-27	\\\\\\\\\\	4/6	15/18	5/6	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
28-32	0/1	1/1	9/9	13/17	9/11	\\\\\\\\\\	\\\\\\\\\
33-36	\\\\\\\\\\	\\\\\\\\\\	1/2	6/7	6/8	1/2	\\\\\\\\\
37-41	\\\\\\\\\\	\\\\\\\\\\	2/2	3/3	1/4	4/7	\\\\\\\\\
42-50	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	1/2	5/7	6/7	1/1
51 +	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	1/2	3/5	0/6

TABLE 32 – Boosters Fit and Combined Belt Fit Good or Fair							
Weight (kg)	Height (cm)						
	112-117	118-124	125-132	133-140	141-147	148-155	156-168
< 23	1/5	11/13	3/3	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
24-27	\\\\\\\\\\	4/6	15/18	2/6	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
28-32	0/1	1/1	9/9	17/17	11/11	\\\\\\\\\\	\\\\\\\\\
33-36	\\\\\\\\\\	\\\\\\\\\\	1/2	5/7	7/8	2/2	\\\\\\\\\
37-41	\\\\\\\\\\	\\\\\\\\\\	1/2	2/3	2/4	2/4	\\\\\\\\\
42-50	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	1/2	0/7	0/7	0/1
51 +	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	0/2	0/5	0/6

As a final look at the relationship between size and belt fit, the apparent cause of poor belt fit in older children, "slouch", is recalled. Table 33 shows what sizes of children tend to slouch in the rear seat alone. A height of 147 cm seems to be the threshold above which slouching is not a problem. This is the same height (determined from Table 30) above which children can use three-point belts effectively.

TABLE 33 – Children who Slouch in Rear Seat							
Weight (kg)	Height (cm)						
	112-117	118-124	125-132	133-140	141-147	148-155	156-168
< 23	4/5	11/13	3/3	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
24-27	\\\\\\\\\\	5/6	16/18	6/6	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\
28-32	0/1	0/1	8/9	15/17	7/11	\\\\\\\\\	\\\\\\\\\
33-36	\\\\\\\\\\	\\\\\\\\\\	2/2	6/7	7/8	1/2	\\\\\\\\\
37-41	\\\\\\\\\\	\\\\\\\\\\	1/2	3/3	2/4	1/7	\\\\\\\\\
42-50	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	1/2	3/7	1/6	0/1
51 +	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	\\\\\\\\\\	1/2	3/5	0/6

4.11 Child Survey Discussion

The anthropometry and belt fit studies of 155 older children have illustrated a great deal about the automotive environment for older children. The following list summarizes the major findings:

- For a given height, children today seem heavier than they were twenty years ago. A more extensive anthropometry study of older children may be appropriate to confirm this.

- The Caravan had the worst shoulder belt fits in the rear seat alone and with the boosters, mostly resulting from the large distance to the shoulder belt in the x-z plane. The Sunbird had the best belt fits in the rear seat and boosters.

- Sitting up straighter improved both lap and shoulder belt fit. Booster and vehicle seat designs that forced children to sit up straight improved belt fit.

- Children who weighed more than the recommended weight still had improved belt fit with belt-positioning booster seats. This conclusion is based only on static belt fit tests and may not be true in dynamic testing.

- Most children who met the weight requirements of the Kangaroo booster did not fit well within the booster.

- The "slouch factor", where children will scoot forward to allow comfortable leg positions rather than sit up straight and put pressure on their legs, appeared to cause poor belt fit frequently.

- Regardless of child size, booster seats greatly improved belt fit over the rear seat alone, going from two-thirds poor to one-fifth. However, the 20% of children who still had poor belt fit with boosters indicated that more improvements could be made.

- It was found that the minimum size child in this study who could use three-point belts alone had a sitting height of 74 cm, standing height of 148 cm, and weight of 37 kg. A child with the height requirements but a smaller weight would also probably have had an acceptable belt fit, while a child with the weight requirement but not the height requirements may not have had an acceptable belt fit with the belt alone.

- Children who could fit well in boosters and had good/fair belt fits were generally 36 kg or less. Weight seemed to be the most critical factor, since these children had sitting heights which varied from 58 to 76 cm, and standing heights which ranged from 117 to 152 cm.

5.0 REFERENCES

1. National Accident Sampling System Data Collection, Coding, and Editing Manual, U. S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, 1991.

2. SAS User's Guide, SAS Institute Inc., 1985.

3. Shah, B. V., et al., SUDAAN User's Manual, Research Triangle Institute, 1991.

4. Ott, L., Larson, R.F., and Mendenhall, W., Statistics, A Tool for the Social Sciences, PWS Publishers, 1987.

5. Natralla, M. G., Experimental Statistics, U.S. Department of Commerce, 1966.

6. Snyder, R.G., Schneider, L.W., Owings, C.L., Reynolds, H.M., Golomb, D.H., Schork, M.A., "Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design," Highway Safety Research Institute, The University of Michigan, UM-HSRI-77-17, May 1977.

7. Hamill, P.V.V., Drizd, T.A., Johnson, D.L., Reed R.B., Roche, A.F., and Moore, W.M., "Physical growth: National Center for Health Statistics Percentiles," AMJ CLIN NUTR 32:607-627, 1979.

8. MacLaughlin, T.F., Sullivan, L.K., and O'Connor, C.S., "Rear Seat Submarining Investigation," National Highway Traffic Safety Administration, DOT HS-807-347, May 1988.

APPENDIX A

For the statistical analysis in each table, D.O.F. designates the degrees of freedom for the table. X^2 is the chi-squared test statistic calculated for the table. $X^2_{.95}$ is the chi-squared test statistic for alpha = 0.05 and the pertinent number of degrees of freedom. If X^2 is less than than $X^2_{.95}$, differences in the two distributions under comparison were caused by chance and are not statistically significant. If the overall distributions were statistically different, a Bonferroni t-test comparison was used to determine which categories within the distributions were significant. For each individual comparison noted as different, the p-value is no greater than 0.025.

Table 1: Restraint Type of Older and Younger Children in Accidents						
Restraint Type	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Unrestrained	782	629	214611.9	188293.3	38.6	70.7
Lap Belt Only	434	148	149509.4	144618.7	26.9	34.6
Lap/Shoulder Belt	385	210	147057.2	72210.0	26.5	9.9
Other/Unknown Belt	52	46	13922.3	14705.0	2.5	2.0
Child Seats	7	578	1940.1	253491.8	0.3	34.6
Unknown	122	148	28260.9	58876.9	0.3	9.9
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	5	54.9	11.07	UNRESTRAINED, LAP BELT ONLY, LAP/SHOULDER BELTS, and CHILD SEATS differ		

Table 2: Injury Frequency of Older and Younger Restrained Children in Accidents						
Number of Injuries	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
None	413	717	195218.4	342990.6	62.5	70.7
Few (1,2,3)	352	403	98303.5	120413.0	31.5	24.8
Several (4,5,6,7)	64	62	10801.9	7794.0	3.5	9.9
Many (8 and more)	49	62	8105.2	13827.9	2.6	2.9
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	3	12.2	7.81	SEVERAL differs		

Table 3: Injury Frequency of Older and Younger Unrestrained Children in Accidents						
Number of Injuries	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
None	223	218	78080.2	83078.2	36.4	44.1
Few (1,2,3)	378	279	109514.4	89818.1	51.0	47.7
Several (4,5,6,7)	116	36	20418.7	6783.5	9.5	3.5
Many (8 and more)	346	43	6598.5	8686.9	3.1	0.1
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	3	8.9	7.81	SEVERAL differs		

Table 4: Maximum Injury Severity of Older and Younger Restrained Children in Accidents						
Maximum Injury Severity (MAIS)	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
0	340	218	195651.1	343319.2	62.8	70.8
1	346	394	96927.4	120140.1	31.1	24.8
2	17	48	8722.9	5864.4	2.8	1.2
7	17	18	1404.9	2282.6	0.5	0.5
7	2	7	268.0	783.4	0.1	0.2
6	7	7	1404.9	223.2	0.1	0.0
6	1	7	104.9	303.7	0.0	0.1
7	346	36	7939.9	11697.1	2.8	2.4
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	7	17.1	14.07	MAIS 0 and MAIS 2 differ		

Table 5: Maximum Injury Severity of Older and Younger Unrestrained Children in Accidents						
Maximum Injury Severity (MAIS)	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
0	227	223	78523.4	83708.2	36.7	44.6
2	382	251	118303.4	85023.0	55.2	45.3
2	82	52	7761.0	6603.1	3.6	3.5
3	32	32	3223.5	2185.2	1.5	1.2
3	5	1	345.8	643.2	0.2	0.3
5	5	1	369.0	405.0	0.2	0.2
5	4	7	154.4	305.7	0.1	0.2
3	43	14	5467.3	8703.7	2.6	3.5
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	7	5.2	14.07	No categories differ		

Table 6: Severity of Injuries Received by Older Children						
Injury Severity (AIS)	Sample Size		Weighted Size		Distribution	
	Unrestrained	Restrained	Unrestrained	Restrained	Unrestrained	Restrained
1	1307	886	266019.8	180011.7	92.3	89.0
2	160	111	12753.7	15011.5	0.1	0.1
3	76	14	5225.7	3052.4	0.1	1.5
4	20	8	1001.2	485.9	0.1	0.1
5	6	8	386.3	535.1	0.1	0.3
6	6	1	154.4	104.9	0.1	0.1
2	14	14	2721.3	3073.4	0.1	1.5
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	18	17.6	28.87	No categories differ		

Table 7: Body Region Injured for Restrained and Unrestrained Older Children						
Body Region	Sample Size		Weighted Size		Distribution	
	Unrestrained	Restrained	Unrestrained	Restrained	Unrestrained	Restrained
Head	260	139	35246.4	22865.8	12.2	11.3
Face	536	347	123393.7	80901.5	42.8	40.0
Neck	58	91	12995.6	15251.6	4.5	7.5
Thorax	260	91	24020.0	18887.6	8.3	9.3
Pelvis/Abdomen	58	170	7573.4	21825.4	2.6	10.8
Whole Body	52	22	10091.9	2533.1	4.5	9.3
Lower Extremities	291	139	44263.0	27902.8	10.1	13.8
Upper Extremities	167	91	28988.4	11971.5	10.1	40.0
Unknown	16	3	1690.0	135.6	0.6	0.1
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8	23.0	15.51	PELVIS/ADBDOMEN and WHOLE BODY differ		

Table 8: System/Organ Injured for Restrained and Unrestrained Older Children						
System/Organ Injured	Sample Size		Weighted Size		Distribution	
	Unrestrained	Restrained	Unrestrained	Restrained	Unrestrained	Restrained
All systems	7	1	482.2	104.9	0.2	0.1
Brain	97	57	11865.0	8437.1	4.1	0.1
Digestive	24	15	3255.8	1188.4	1.1	0.1
Eye	48	30	8391.6	10084.3	2.9	0.1
Integumentary	1102	751	217292.0	148602.4	75.4	73.5
Muscles	53	15	14871.4	11170.9	5.2	5.5
Skeletal	170	101	13865.0	14492.4	6.3	7.2
Other	73	43	11419.2	4875.7	4.0	1.6
Unknown	13	15	2569.7	3318.8	0.1	1.6
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8	4.9	15.51	No categories differ		

Table 9: Lesion Type for Restrained and Unrestrained Older Children						
Lesion Type	Sample Size		Weighted Size		Distribution	
	Unrestrained	Restrained	Unrestrained	Restrained	Unrestrained	Restrained
Abrasion	358	193	50299.2	30608.7	17.4	15.1
Contusion	525	408	129201.8	103039.7	43.8	50.9
Laceration	334	165	53960.7	28583.4	18.7	14.1
Fracture/Dislocation	162	408	16229.0	14500.6	5.6	7.2
Strain	80	47	14691.1	11135.9	5.1	5.5
Concussion	80	408	10994.0	7969.4	3.8	3.9
Other	44	49	8283.0	2632.7	2.9	1.9
Unknown	35	24	4603.7	3804.5	3.8	1.9
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	7	10.1	14.07	No categories differ		

Table 10: Injury Frequency of Restrained and Unrestrained Older Children						
Number of Injuries	Sample Size		Weighted Size		Distribution	
	Unrestrained	Restrained	Unrestrained	Restrained	Unrestrained	Restrained
None	223	408	78080.2	193702.5	18.7	62.4
Few (1,2,3)	378	350	109514.4	97879.3	51.0	31.5
Several (4,5,6,7)	116	64	20418.7	10801.9	9.5	3.5
Many (8 and more)	80	49	6598.5	8105.2	3.1	2.6
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	3	20.6	7.81	NONE, FEW, and SEVERAL differ		

Table 11: Severity of Injuries for Restrained Older and Younger Children						
Injury Severity (AIS)	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
3	889	931	180777.9	205986.9	89.0	91.7
7	111	45	15011.5	10129.7	0.1	1.9
3	36	45	3052.4	4274.7	1.5	1.9
4	5	24	485.9	1709.0	0.2	0.8
5	1	8	535.1	663.9	0.3	0.3
6	1	5	104.9	445.0	0.1	0.8
7	36	10	3073.4	1399.9	1.5	0.6
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	6	10.7	12.59	No categories differ		

Table 12: Body Region Injured for Older and Younger Restrained Children						
Body Region	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Head	139	105	22865.8	28413.5	11.0	12.7
Face	348	468	81243.6	89226.3	40.0	39.7
Neck	91	44	15251.6	8935.5	7.5	4.0
Thorax	91	106	18887.6	18686.7	9.3	8.3
Pelvis/Abdomen	172	105	22249.6	46306.9	11.0	20.6
Whole Body	22	20	2533.1	6086.0	1.2	2.7
Lower Extremities	133	99	27902.8	14889.5	13.7	6.6
Upper Extremities	96	73	11971.5	11394.3	40.0	5.1
Unknown	3	6	135.6	670.4	1.2	3.3
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8	13.2	15.51	No categories differ		

Table 13: System/Organ Injured for Older and Younger Restrained Children						
System/Organ Injured	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
All systems	1	2	104.9	282.6	0.6	0.4
Brain	57	31	8437.1	6983.7	4.2	4.4
Digestive	98	30	1188.4	6206.8	0.6	2.8
Eye	48	37	10426.3	7848.0	5.1	3.5
Integumentary	753	831	149026.3	184853.0	73.4	82.3
Muscles	48	20	11170.9	3969.9	5.5	2.8
Skeletal	101	91	14492.4	9902.3	7.1	4.4
Other	43	36	4875.7	3073.2	2.4	2.8
Unknown	15	11	3318.8	1489.6	1.6	0.4
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8	22.0	15.51	DIGESTIVE differs		

Table 14: Lesion Type for Older and Younger Restrained Children						
Lesion Type	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Abrasion	193	248	30608.7	53594.6	15.1	23.9
Contusion	446	445	103805.9	106905.8	51.1	47.6
Laceration	165	234	28583.4	39156.8	14.1	17.4
Fracture/Dislocation	98	94	14500.6	10043.6	2.4	4.5
Strain	43	17	11135.9	3508.0	5.5	1.5
Concussion	48	40	7969.4	6130.9	1.6	2.7
Other	43	13	2632.7	2799.4	1.9	1.2
Unknown	24	17	3804.5	2470.1	1.9	1.5
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	7	20.6	14.07	STRAIN differs		

Table 15: Severity of Injuries for Unrestrained Older and Younger Children						
Injury Severity (AIS)	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
1	1776	1254	361215.1	258740.0	91.4	89.9
2	215	175	19710.1	15805.8	5.0	5.5
4	95	71	7243.0	5849.4	1.8	2.0
4	24	13	1458.4	1740.6	0.1	0.5
5	9	13	549.1	574.6	0.1	0.2
4	4	11	154.4	478.1	0.0	0.2
7	25	23	4659.0	4629.3	1.2	1.6
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	6	3.5	12.59	No categories differ		

Table 16: Body Region Injured for Older and Younger Unrestrained Children						
Body Region	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Head	337	296	49286.7	38171.3	42.5	13.3
Face	337	626	167711.1	135377.5	42.5	47.0
Neck	70	54	18365.2	6254.1	7.8	0.8
Thorax	337	143	30668.2	17520.7	7.8	0.8
Pelvis/Abdomen	148	48	20385.4	38953.4	5.2	13.5
Whole Body	70	48	12343.9	8338.2	3.1	2.9
Lower Extremities	369	216	59109.5	25903.1	15.0	9.0
Upper Extremities	215	121	35345.8	15029.0	7.8	5.2
Unknown	19	11	1773.3	2270.7	3.1	0.8
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8	13.2	15.51	No categories differ		

Table 17: System/Organ Injured for Older and Younger Unrestrained Children						
System/Organ Injured	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
All systems	7	5	482.2	360.7	2.9	0.1
Brain	129	103	17278.5	10078.0	4.4	4.5
Digestive	33	35	4257.7	8214.8	4.1	1.4
Eye	64	50	11422.1	10061.2	2.9	4.5
Integumentary	1493	1128	298835.6	232353.1	75.7	80.7
Muscles	33	21	17751.2	4160.0	4.5	1.4
Skeletal	776	155	25503.5	12837.4	6.5	4.5
Other	129	73	14950.9	4731.2	4.4	1.6
Unknown	24	27	4507.5	5021.7	2.9	1.7
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8			No categories differ		

Table 18: Lesion Type for Older and Younger Unrestrained Children						
Lesion Type	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Abrasion	450	365	63900.6	47738.3	16.2	166
Contusion	776	551	186213.5	142598.9	47.1	49.5
Laceration	413	347	70880.6	64265.3	17.9	22.3
Fracture/Dislocation	217	168	23869.3	13428.7	413	1.2
Strain	70	17	17570.9	3350.8	413	1.2
Concussion	64	74	16200.1	8670.4	4.1	3.0
Other	64	24	9521.5	6333.9	2.4	0.5
Unknown	52	51	6832.6	6333.9	1.7	2.2
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	7	7.4	14.07	No categories differ		

Table 19: Body Region Injured in Mild and Serious Injuries to Older Children						
Body Region	Sample Size		Weighted Size		Distribution	
	AIS 1 & 2	AIS 3,4,5,6	AIS 1 & 2	AIS 3,4,5,6	AIS 1 & 2	AIS 3,4,5,6
Head	110	66	53152.7	4998.2	10.8	44.0
Face	904	0	210205.3	168.8	42.7	0.0
Neck	110	4	28231.5	135.9	0.4	1.2
Thorax	211	18	41032.5	1914.4	8.3	16.8
Pelvis/Abdomen	110	18	29180.2	1346.1	8.3	11.8
Whole Body	81	8	13357.9	149.7	211	4.9
Lower Extremities	412	28	73831.4	2095.5	10.0	18.4
Upper Extremities	267	8	40972.0	168.0	8.3	4.9
Unknown	20	0	1874.5	0.0	0.4	0.0
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8	16.6	15.51	HEAD, FACE, and NECK differ		

Table 20: System/Organ Injured in Mild and Serious Injuries to Older Children						
System/Organ Injured	Sample Size		Weighted Size		Distribution	
	AIS 1 & 2	AIS 3,4,5,6	AIS 1 & 2	AIS 3,4,5,6	AIS 1 & 2	AIS 3,4,5,6
All systems	4	0	354.6	232.4	0.1	2.0
Brain	116	0	17368.9	3433.2	3.5	30.2
Digestive	34	6	4131.1	620.1	0.8	5.5
Eye	82	0	18973.3	0.0	0.8	0.0
Integumentary	1917	7	379967.4	324.9	77.3	2.9
Muscles	102	0	26370.5	0.0	0.1	0.0
Skeletal	226	58	30161.1	4224.7	6.1	37.2
Other	77	42	14265.7	2534.4	2.9	22.3
Unknown	1	0	245.4	0.0	0.0	0.0
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	8	22.1	15.51	All categories except ALL SYSTEMS, DIGESTIVE, and UNKNOWN differ		

Table 21: Lesion Type of Mild and Serious Injuries to Older Children						
Lesion Type	Sample Size		Weighted Size		Distribution	
	AIS 1 & 2	AIS 3,4,5,6	AIS 1 & 2	AIS 3,4,5,6	AIS 1 & 2	AIS 3,4,5,6
Abrasion	189	0	82819.6	0.0	16.8	0.0
Contusion	985	22	240476.9	1525.7	48.9	13.4
Laceration	489	18	84385.8	1602.1	17.2	14.1
Fracture/Dislocation	213	506	28261.2	4246.2	5.7	37.3
Strain	97	0	26155.3	0.0	0.4	0.0
Concussion	0.4	18	17368.9	2094.5	3.5	18.4
Other	97	17	10221.5	929.4	0.4	8.2
Unknown	19	18	2149.0	971.8	0.4	8.5
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	7	23.5	14.07	All categories except LACERATION and OTHER differ		

Table 22: Change in Velocity of Accidents with Children						
Change in Velocity (mph)	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Unknown	985	1163	355252.9	420138.6	64.0	57.4
0-10	189	187	79167.8	134435.6	14.3	18.4
11-20	985	506	100206.5	159271.9	16.3	21.8
21-30	127	0.0	17977.0	15145.4	3.2	2.1
> 30	25	39	2697.6	3204.4	0.5	0.4
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	4	5.1	9.49	No categories differ		

Table 23: Vehicle Type in Accidents with Children						
Vehicle Type	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Passenger	1380	1619	456293.4	607123.6	82.2	82.9
Psuedo-passenger	1	0	30.9	0.0	0.0	0.0
Utility	73	84	16160.7	24542.5	2.9	3.4
Vans	170	156	40001.6	47469.6	7.2	6.5
Light Trucks	158	156	42815.3	53060.0	7.7	7.2
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	4	1.6	9.49	No categories differ		

Table 24: Accident Type in Accidents with Children						
Accident Type	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
No impact	1	2	122.6	5713.2	0.0	1.4
Off-road	278	340	73605.8	189250.6	13.3	15.8
Forward (1 driver)	25	32	4905.3	15033.2	0.9	1.4
Rear-end	284	326	134497.2	285054.1	24.2	20.6
Forward (same direction)	1	0	5792.7	5792.7	0.9	1.4
Sideswipe (same direction)	73	35	7733.8	15655.9	2.2	1.1
Head-on	73	133	24567.4	59407.1	4.4	4.8
Forward (opp. direction)	9	6	1993.4	4713.1	0.9	1.4
Sideswipe (opp.direction)	72	84	14777.6	37744.6	0.9	3.1
Side	847	957	259475.9	614745.0	46.7	48.5
Other	117	105	27830.2	54388.1	5.0	3.1
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	10	7.2	18.31	No categories differ		

Table 25: Seat Position of Children						
Seat Position	Sample Size		Weighted Size		Distribution	
	Older	Younger	Older	Younger	Older	Younger
Front Driver	5	3	3843.0	483.3	0.7	0.1
Front Center	80	120	21467.5	45759.3	3.9	9.1
Front Passenger	603	513	213310.5	197597.1	38.4	27.0
Rear Passenger	778	904	229746.5	344884.2	41.4	47.1
Rear Center	177	267	45621.3	85737.1	8.2	11.7
Other	59	120	18617.0	33442.2	4.1	4.6
Unknown	80	75	22696.0	24292.5	4.1	3.3
Statistical Analysis	D.O.F.	X^2	$X^2_{.95}$	Statistically Different?		
	6	15.3	12.59	FRONT PASSENGER differs		

APPENDIX B

Photos Illustrating Different Film Ratings

Figure B1 -- Shoulder belt fit: in face

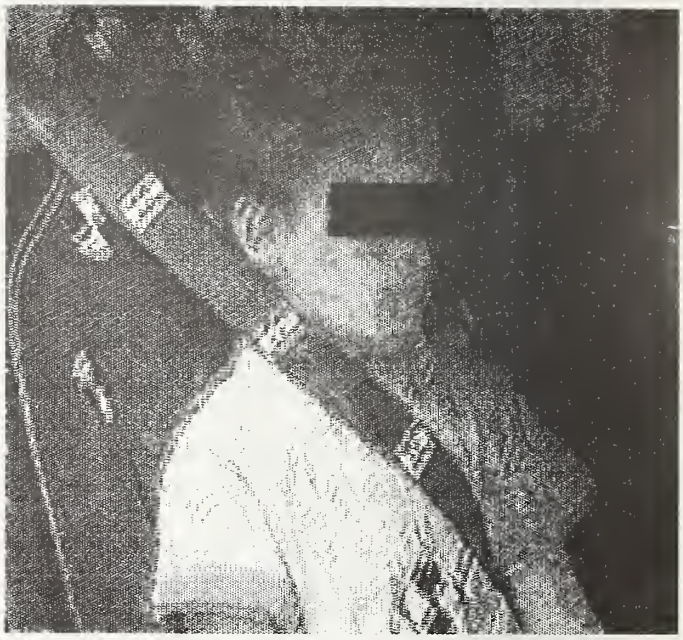

Figure B2 -- Shoulder belt fit: against neck

Figure B3 -- Shoulder belt fit: on shoulder, but too close to neck

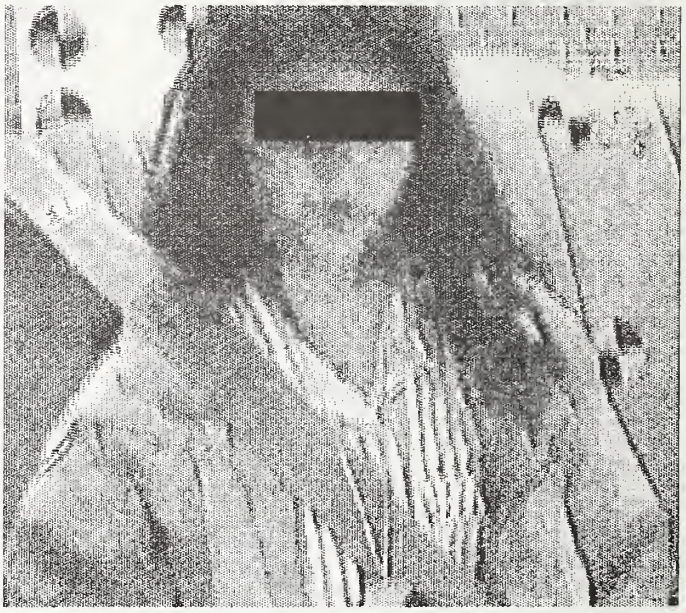

Figure B4 -- Shoulder belt fit: centered on shoulder

Figure B5 -- Shoulder belt fit: on shoulder, but too close to arm

Figure B6 -- Lap belt fit: flat across legs

Figure B7 -- Lap belt fit: low over pelvis

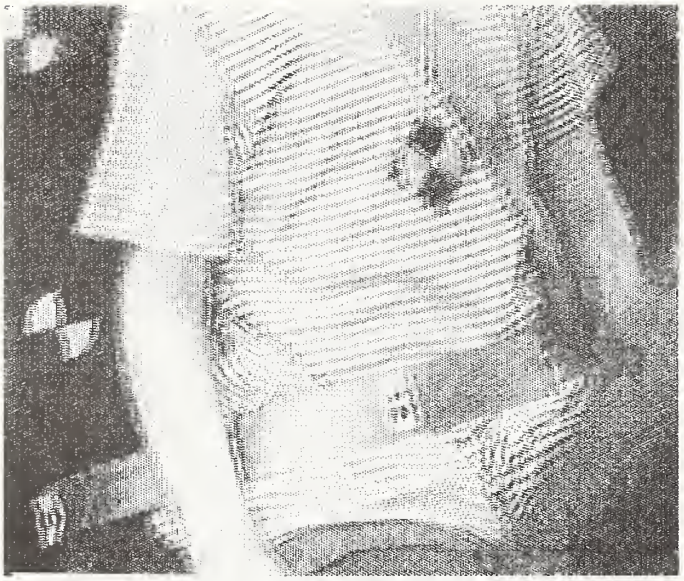

Figure B8 -- Lap belt fit: over pelvis

Figure B9 -- Lap belt fit: over abdomen

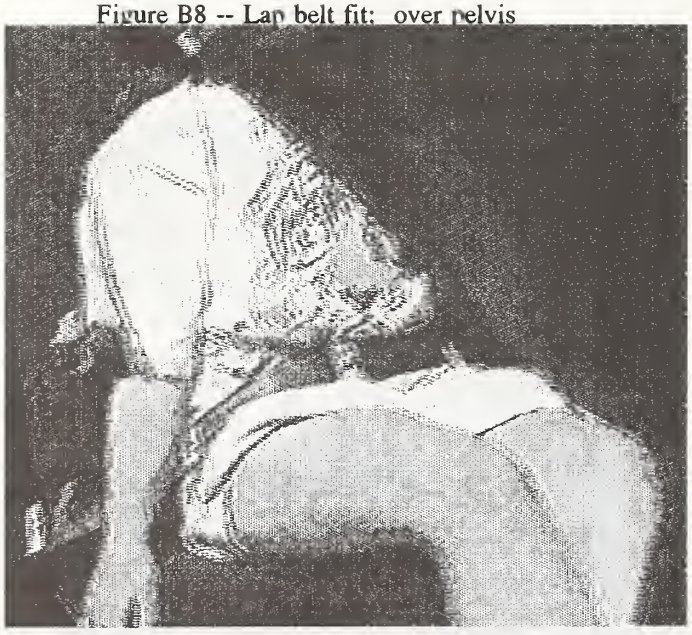

Figure B10 -- Lap belt fit: approaching ribcage

Figure B11 -- Slouch factor: sitting up straight

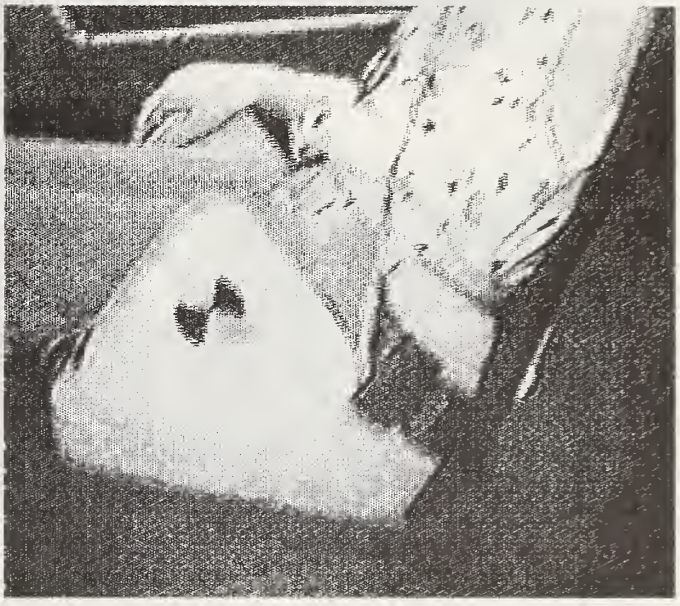

Figure B12 -- Slouch factor: sitting up almost straight

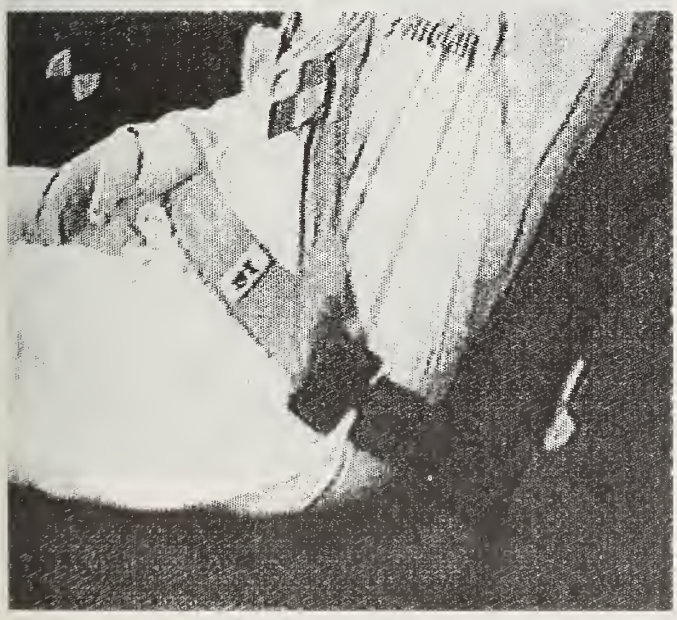

Figure B13 -- Slouch factor: slouching somewhat

Figure B14 -- Slouch factor: slouching a lot

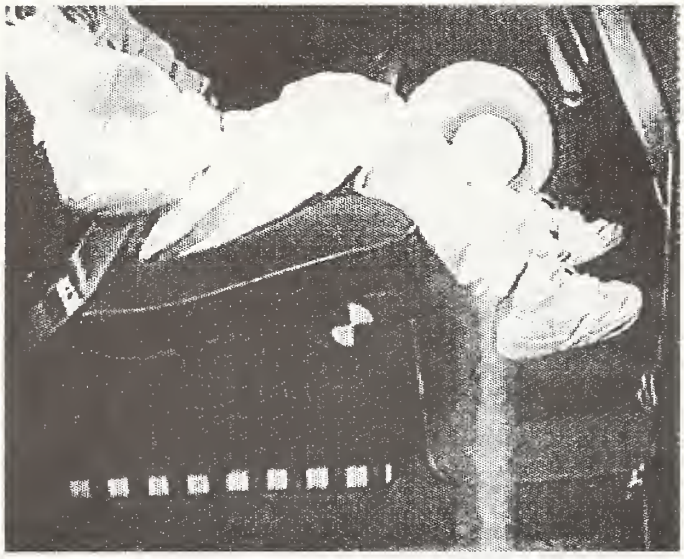

Figure B15 -- Leg position: significantly above horizontal

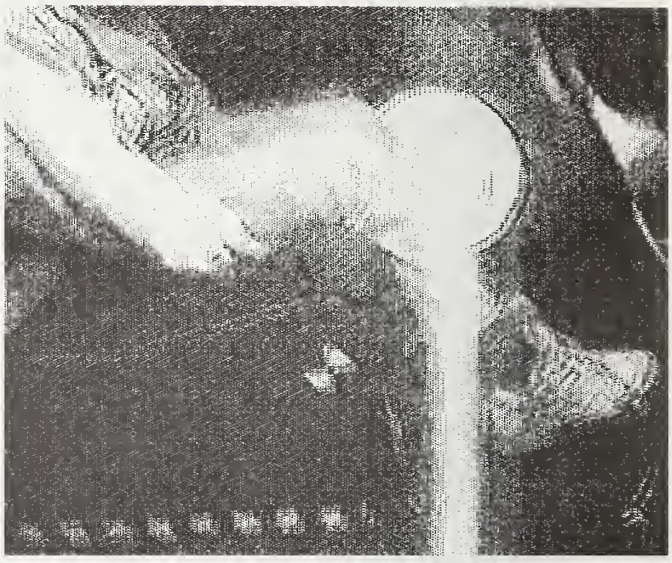

Figure B16 -- Leg position: slightly above horizontal

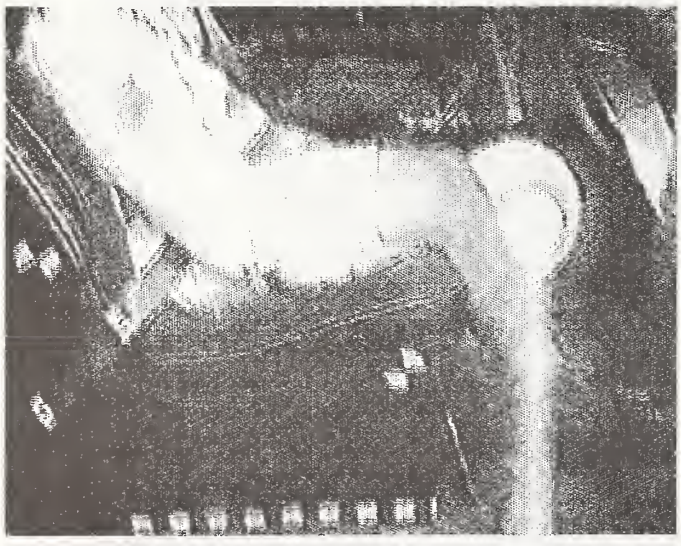

Figure B17 -- Leg position: horizontal

Figure B18 -- Leg position: slightly below horizontal

Figure B19 -- Leg position: significantly below horizontal

APPENDIX C

DESCRIPTION OF VARIABLES FOR EACH OBSERVATION

OBS: Observation number

CODE: Three-character code which identifies the volunteer

VEHICLE: Test vehicle, either Taurus, Sunbird, or Caravan

SEAT: Test seat, either rear, Volvo, Kangaroo, Century, front forward (F), or front rearward (B).

ENTRY: Observation number for a single volunteer (usually between 1 and 11)

GRADE: Child's grade in school

SEX: Gender, either Boy or Girl

AGE: Calculated age as of March 1, 1993

WT: Weight

HT: Height

SITHT: Sitting height

CLASS: Original volunteer classification scheme

A: less than 119 cm or less than 25 kg

B: between 119 cm and 150 cm and less than 31.5 kg

C: between 119 cm and 150 cm and greater than 31.5 kg

D: greater than 150 cm or greater than 43 kg

SHR: Sitting height/height ratio

WTHT: Weight-to-height ratio

WTCLS: Weight class, with the following divisions: < 23 kg, 24-27, 28-32, 33-36, 37-41, 42-50, and 51+

HTCLS: Height class, with the following divisions, 112-117 cm, 118-124, 125-132, 133-140, 141-147, 148-155, 156-168

SHCLS: Sitting height class, with the following divisions, 58-63, 64-68, 69-73, 74-78, 79+

TYPE: Specialized classification scheme, to allow analysis of groups of children with similar physical characteristics. The groups consist of:

1: 6YO Dummy-sized children

2: Adult-sized children; could not fit in any boosters

3: Weight 30-39 kg, English weight/height ratio 1.3 to 1.5

4: Children who could fit in some, but not all boosters

5: Children who could fit in all boosters and weighed over 39 kg

6: Weight 30-39 kg, English weight/height ratio < 1.3

7: Weight 30-39 kg, English weight/height ratio > 1.5

8: Weight < 30 kg, English weight/height ratio < 1.2

9: Weight < 30 kg, English weight/height ratio > 1.2

10: Weight < 30 kg, English weight/height ratio = 1.2

FAVRITE: Child's favorite seat for a particular vehicle, using the following codes
1:Rear Seat 2:Volvo 3:Kangaroo 4:Century 5:Front/Front forward 6:Front rearward 7:All boosters 8:All the same 9-15: Various combinations of boosters and rear seat

BSTRFIT, LAPFIT, SHLDRFIT, SLOUCH, VSITHT, LEGANGLE, FEETPOS, SEATPOS, CLOTHLAP, CLOTHSHL, CHEST, BELT, TARGET: See report text for description

BELTFIT: Combined belt fit rating, using the following scheme
1: Good shoulder and lap belt fit (centered on shoulder and horizontal over legs or low over pelvis) 2: Fair shoulder and lap belt fit, or fair/good lap/shoulder belt combination (on shoulder but too close to neck or arm; over pelvis) 3: Poor shoulder and lap belt fit, or fair/poor lap/shoulder belt combination (over arm or against neck or in face; over abdomen or approaching ribcage)

POSTUR: Combined posture rating, considering vehicle sitting height, slouch, and leg angle according to the following scheme
1: Good sitting height, slouch, and leg angle (ears along or below seat back, sitting up straight or almost straight, leg horizontal or slightly above horizontal) 2: Fair sitting height, slouch, and leg angle, or good/fair combinations (slouched somewhat; leg slightly below horizontal or significantly above horizontal) 3: Poor sitting height, slouch, and leg angle, or poor/fair combinations (extremely slouched, leg significantly below horizontal, ears above seat back or higher)

COMBFIT: Combined fit rating, using overall belt fit and posture together
1: Good belt fit and posture 2: Fair/good combinations of belt fit/posture 3: Fair belt fit and posture, or good/poor combinations of belt fit/posture 4: Poor belt fit and posture, or fair/poor combinations of belt fit/posture

DELLAP: Change in lap belt fit relative to rear seat position

DELSHLD: Change in shoulder belt fit relative to rear seat position

DELFIT: Change in combined fit relative to rear seat position

DELSLCH: Change in slouch relative to rear seat position

DELLEG: Change in leg angle relative to rear seat position

DELFT: Change in feet location relative to rear seat position

APPENDIX D

Photos illustrating different booster seat fits

Figure D1 -- Comfortable fit in Volvo

Figure D2 -- Snug fit in Volvo booster

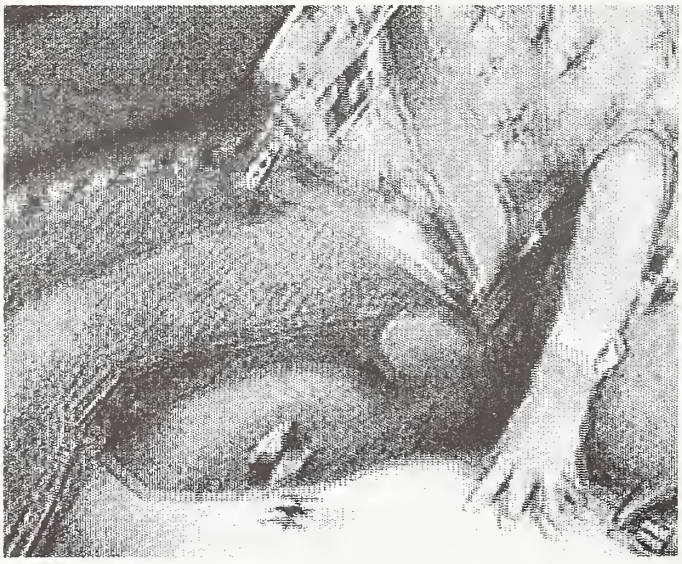

Figure D3 -- Tight fit with Volvo booster

Figure D4 -- Snug fit with Kangaroo booster

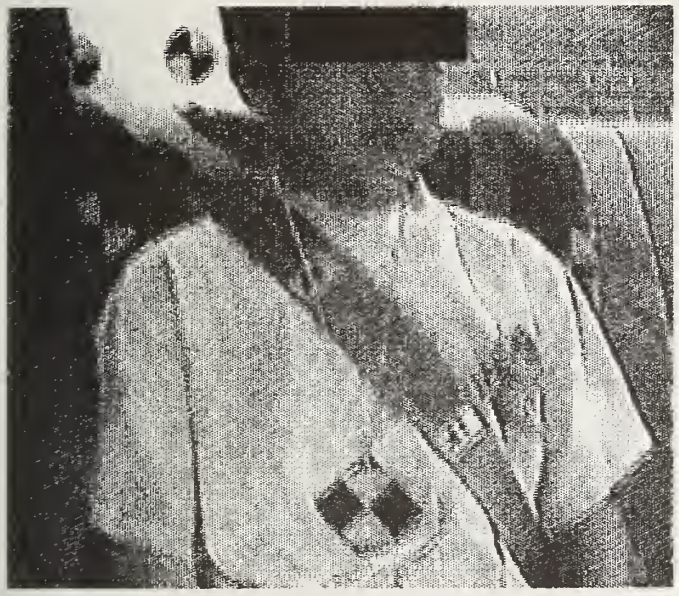

Figure D5 -- Medium fit with Kangaroo booster

Figure D6 -- Tight fit with Kangaroo booster

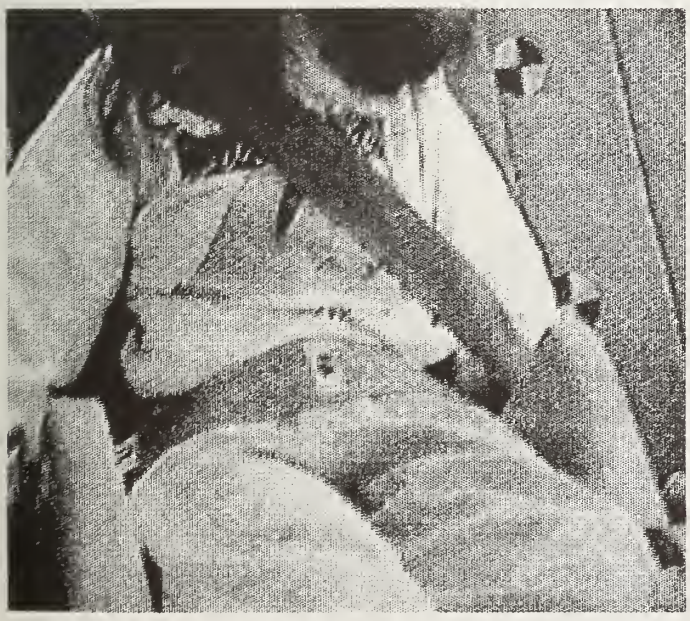

Figure D7 -- comfortable fit in Century CR-3

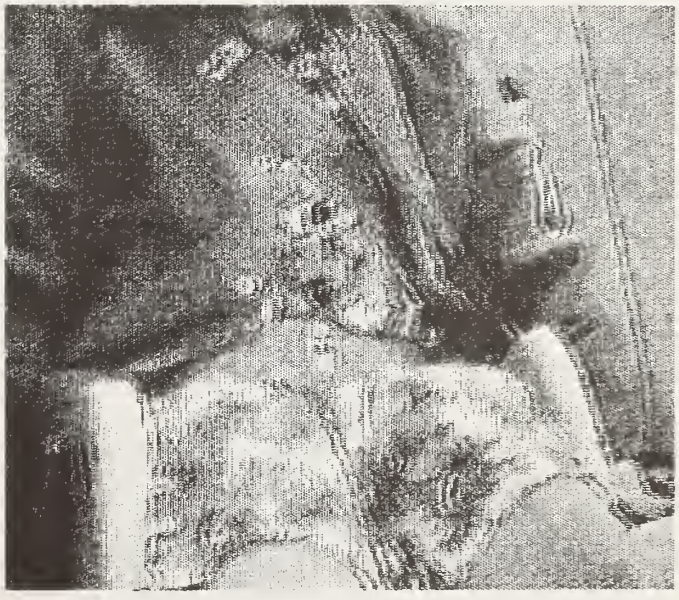

Figure D8 -- Snug fit in Century CR-3

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